The National HVDC centre

our activities, de-risking GB HVDC developments.

The National HVDC Centre

Scottish & Southern Electricity Networks

TRANSMISSION

About us

The National HVDC Centre, GB

Who is the HVDC centre?

And what's our role?

The National HVDC Centre is an Ofgem funded simulation and training facility available to support all GB HVDC schemes.

Ofgem determination takes us from Innovation to BAU for RIIO-T2

The National HVDC Centre

part of Scottish & Southern Electricity Networks

together with nationalgrid SP ENERGY NETWORKS

The National HVDC Centre is part of Scottish & Southern Electricity Networks and is funded through the Electricity Network Innovation Competition as the Multi-Terminal Test Environment (MTTE) Project. Scottish and Southern Electricity Networks is a trading name of Scottish Hydro Electric Transmission plc, Registered in Scotland No. SC213461, having its Registered Office at Inveralmond House, 200 Dunkeld Road, Perth, PH1 3AQ; and is a member of the SSE Group www.ssen.co.uk

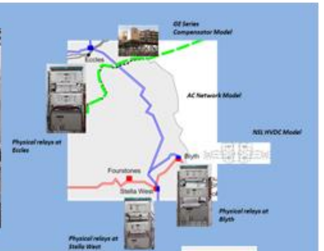
Tools

RTDS and HiL environment

(Enhanced Testing, Multi- Device Grid Integration, Protection & Control system, modification acceptance, post event investigation validation analysis)

Simulation environment (RTDS->EMT->RMS)

(Validation, Benchmarking, analysis)



RTDS Technologies PSCAD PSS®E DIgSILENT

Systems

Collaboration

(models, analysis, direction)

Codes, Standards, R&D

(expert input, workstream support)

The National HVDC Centre; SP ENERGY NETWORKS; Scottish & Southern Electricity Networks; nationalgrid; nationalgridESO; Grid Code; cigre; entsoe; EPRI ELECTRIC POWER RESEARCH INSTITUTE; PROMOTioN PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Skills

Structured Training

(Webinars, Courses, Application & Implementation)

Control training

(Operator Certification, Scenario Planning, Updates)

Research dissemination

(Analysis Techniques, Risk Quantification, Solution Definition)

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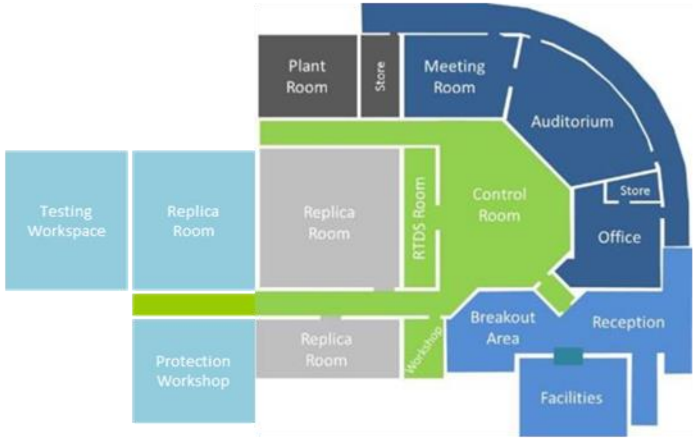
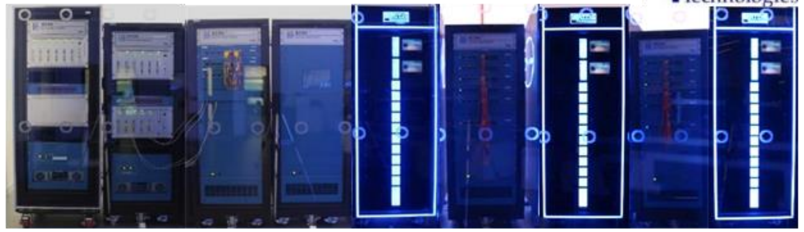
What is the HVDC centre?

A simulation hosting facility to manage complete network and device study.

A purpose-built facility, with state-of-the-art simulation capabilities.



RTDS Technologies



RTDS System

Caithness Moray Shetland Other

HVDC Replicas

Control Hardware

Protection Relays

"we consider the Centre provides a neutral and confidential environment for IP protection, and is important in bridging knowledge gaps between relevant parties and allows for the robust investigations needed to mitigate risks associated with developing HVDC scheme"

"We are of the view that the role of the Centre improves the integrity and security of the network, as it provides a testing environment where various HVDC schemes and projects can be studied, to anticipate and mitigate against potential risks".

ofgem

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Development of HVDC Connections in GB

Current HVDC in GB

7 HVDC Links - Totalling: 8 GW

Interconnectors:
1) Cross Channel (IFA)
2) Moyle
3) BritNed
4) EWIC

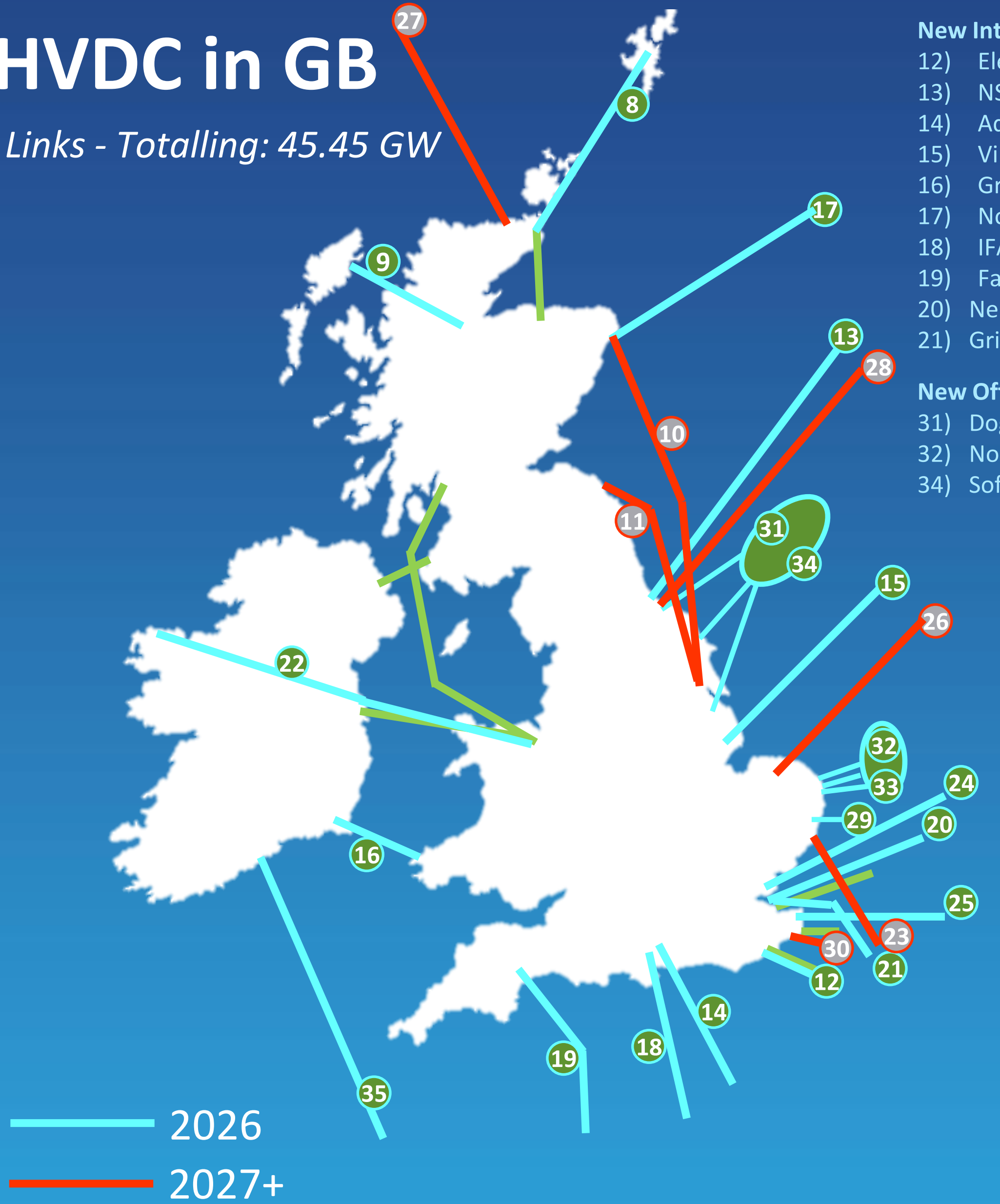
New Interconnector:
5) Nemo

New Embedded Links:
6) Caithness – Moray
7) Western Link

Source: National Grid Interconnector Register 01 08 2019

Future HVDC in GB

Up to 34 HVDC Links - Totalling: 45.45 GW



New Island Links
8) Shetland
9) Western Isles

New Interconnectors
12) ElecLink
13) NSL
14) Aquind
15) Viking
16) GreenLink
17) NorthConnect
18) IFA2
19) Fablink
20) NeuConnect
21) Gridlink

New Offshore Wind Connections
31) Dogger Bank
32) Norfolk Vanguard
34) Sofia

New Embedded Links
10) Eastern Link 2
11) Eastern Link 1

Additional Interconnectors
26) Aminth
27) Atlantic Super Connection
28) Continental Link

Inverter based technology– its evolution.

- **Converter technology, unlike synchronous and passive electrical technology is driven by:**
  - **Capability to define robust control and protection strategies**
  - **Tolerances and topologies of the semi-conductor technologies employed**
  - **User requirements.**
- **Each control & protections strategy exists in priority to another and transitions can occur within microsecs derived from grid measurement & prediction**
- **These and the specifics of converter structure and its relationship to specification are areas of heavily guarded IP & will not be reflected in detail within models exchanged.**

Power System performance area	Legacy (early/ small scale)	2nd Generation Grid follow & withstand	3rd Generation Grid follow & support	4th Generation; Grid forming, stabilising
Fault ride through and recovery	None/ limited	Yes	Yes	**Yes**
RoCoF & Vector Shift sensitivity	LoM and control-based sensitivities	Different LoM considerations, control based sensitivity remain	Lesser control based sensitivities, potentially still LoM	**No**
Steady state and dynamic voltage support	None/ limited	Yes		**Yes**
Fast fault current & transient voltage support	no	no	Yes, but may not be aligned with protection need	**Yes- aligned with protection need**
Low SCL resilience	no	no	Yes but may require careful tuning	**Yes**
Inertial voltage& frequency support	no	no	No	**Yes –inherent to control concept**
Black start capable	no	no	Potential options	
Proportions connecting on GB	c.20%	c.30%	c. 50%	**>1%, more to come?**

These are facets of control and protection capabilities and priorities….

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2) *Inverter based technology*– Network performance significance.

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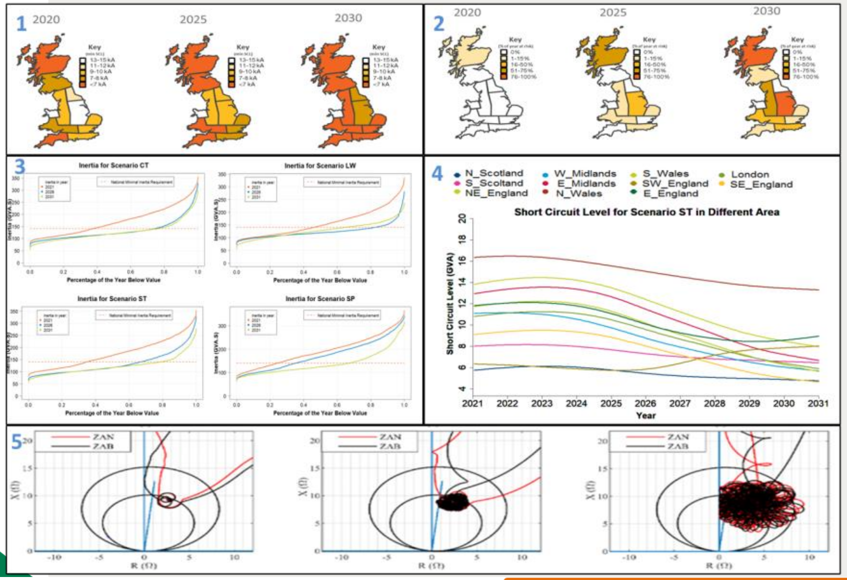
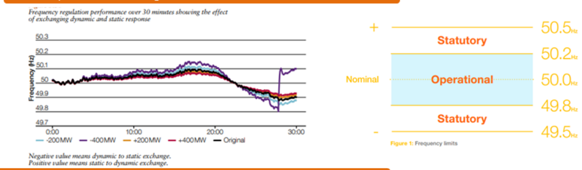


Impact of declining Short circuit level (A System Operability Framework Document), National Grid ESO, download (nationalgrideso.com)

1. Phase Locked Loop Risk
2. Declining Short-circuit level
3. Mean Short Circuit Level for scenario System Transformation in different areas
4. Annual distribution of the inertia- where this is influences performance- not just the fault current, but its predictability!
5. Worsening Protection Performance on decreased Short-circuit level and increased converter penetration

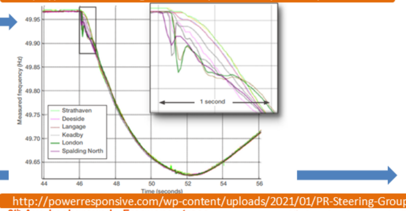
https://www.nationalgrideso.com/document/63481/download

Minimising frequency "drift"



https://www.nationalgrideso.com/document/144441/download

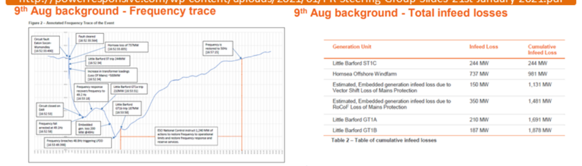
Responding to frequency movement (Frequency moves differently across the system during an event)



Damping frequency following an event

http://powerresponsive.com/wp-content/uploads/2021/01/PR-Steering-Group-Slides-21st-January-2021.pdf

Containing frequency movement (avoiding cascade loss)



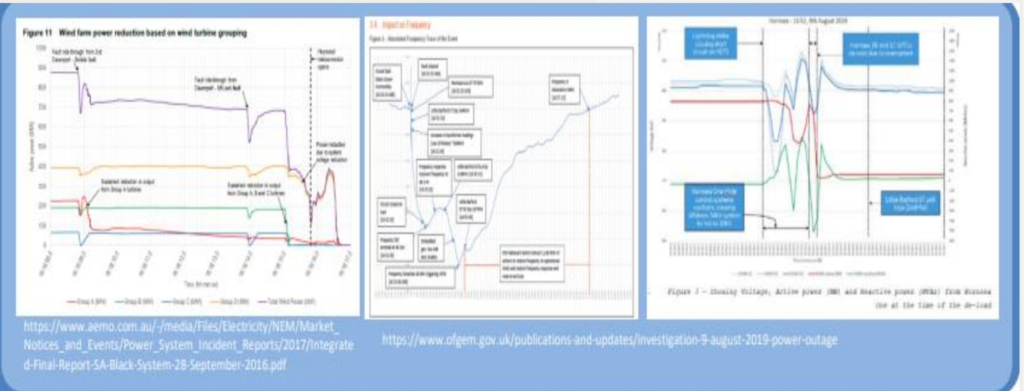
Key ingredients today

System inertia	Frequency regulation	Static and dynamic responses

Single point failure risks, as network conditions change-and more complex designs emerge.

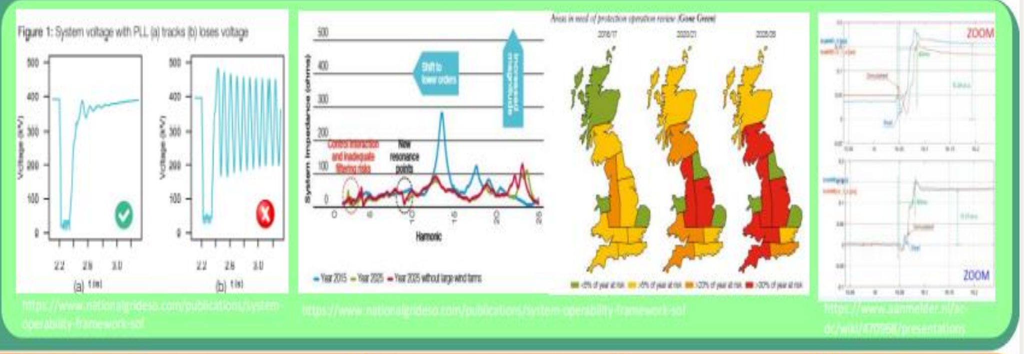
Tracking and managing changes occurring over lifetime.

Completeness of information and analysis possible ahead of connection.



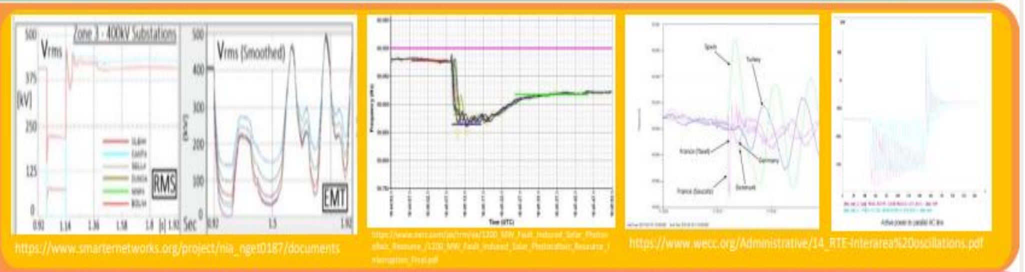
Hidden project interactions.

New vulnerabilities...



Hidden project behaviours.

Completeness of codes & standards & Data Exchange.



Convertor performance can be part of the problem.... or part of the solution.

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Our projects-

Some examples of Delivering de-risked solutions..

Caithness- Moray- Shetland

Europe's 1st multi-terminal VSC-HVDC project

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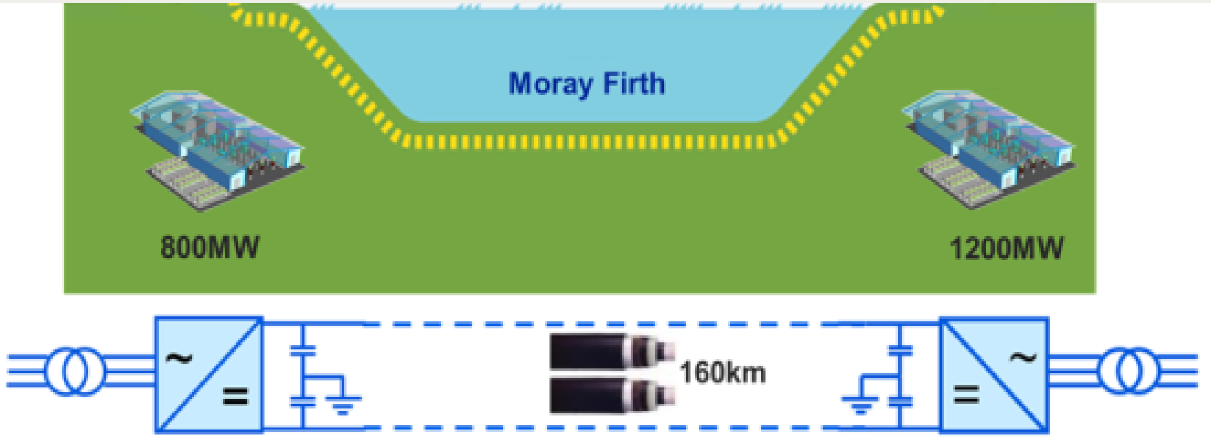
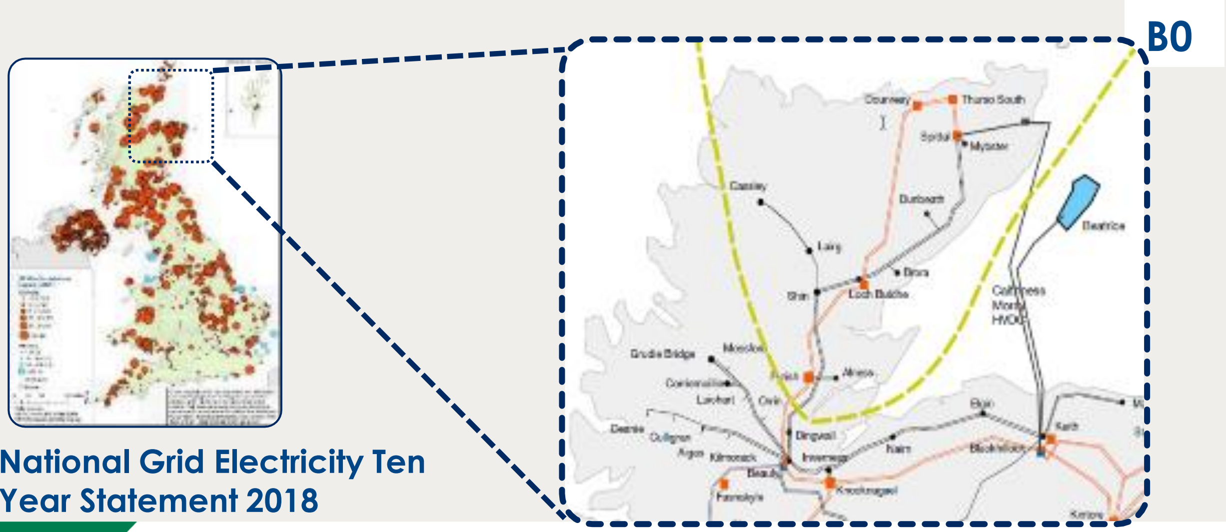
CMS – *Main Project Outline*

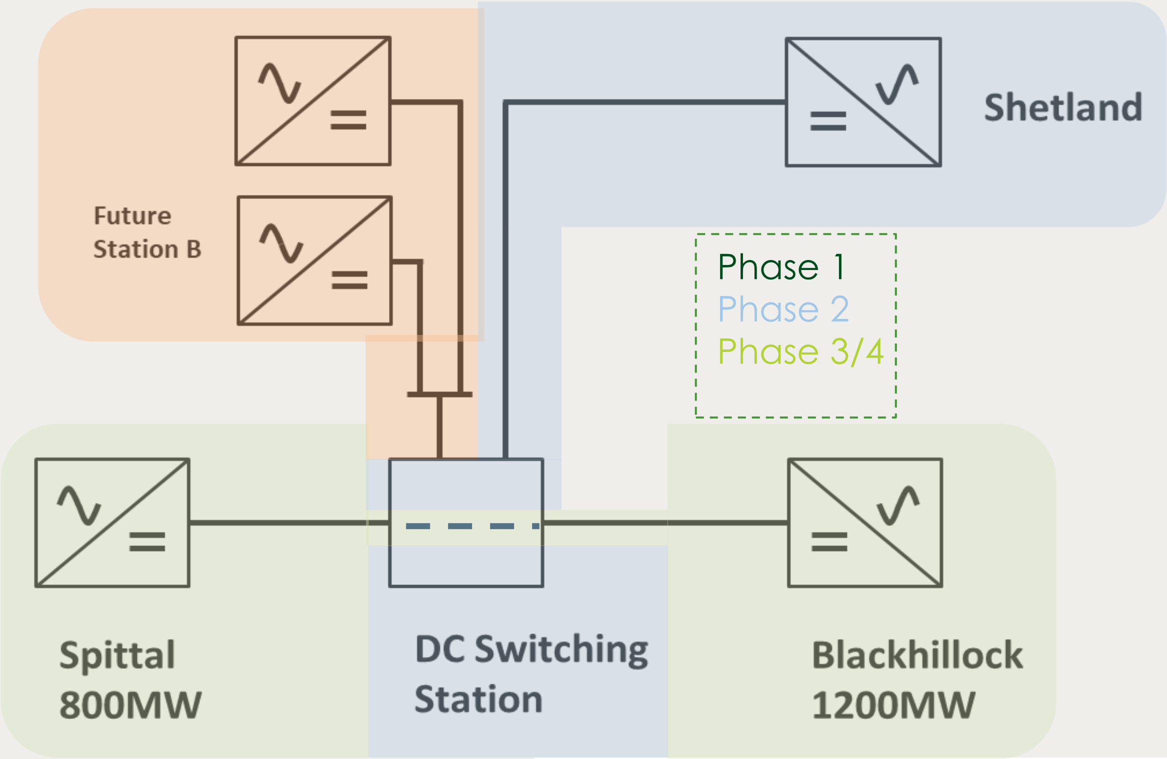
- Phase 1 is a point-to-point HVDC link between Spittal (in Caithness) and Blackhillock (in Moray)





National Grid Electricity Ten Year Statement 2018

- Phase 2 is planned as an extension to Shetland and the introduction of a DC switching station
- Full design allows for further terminals to be incorporated



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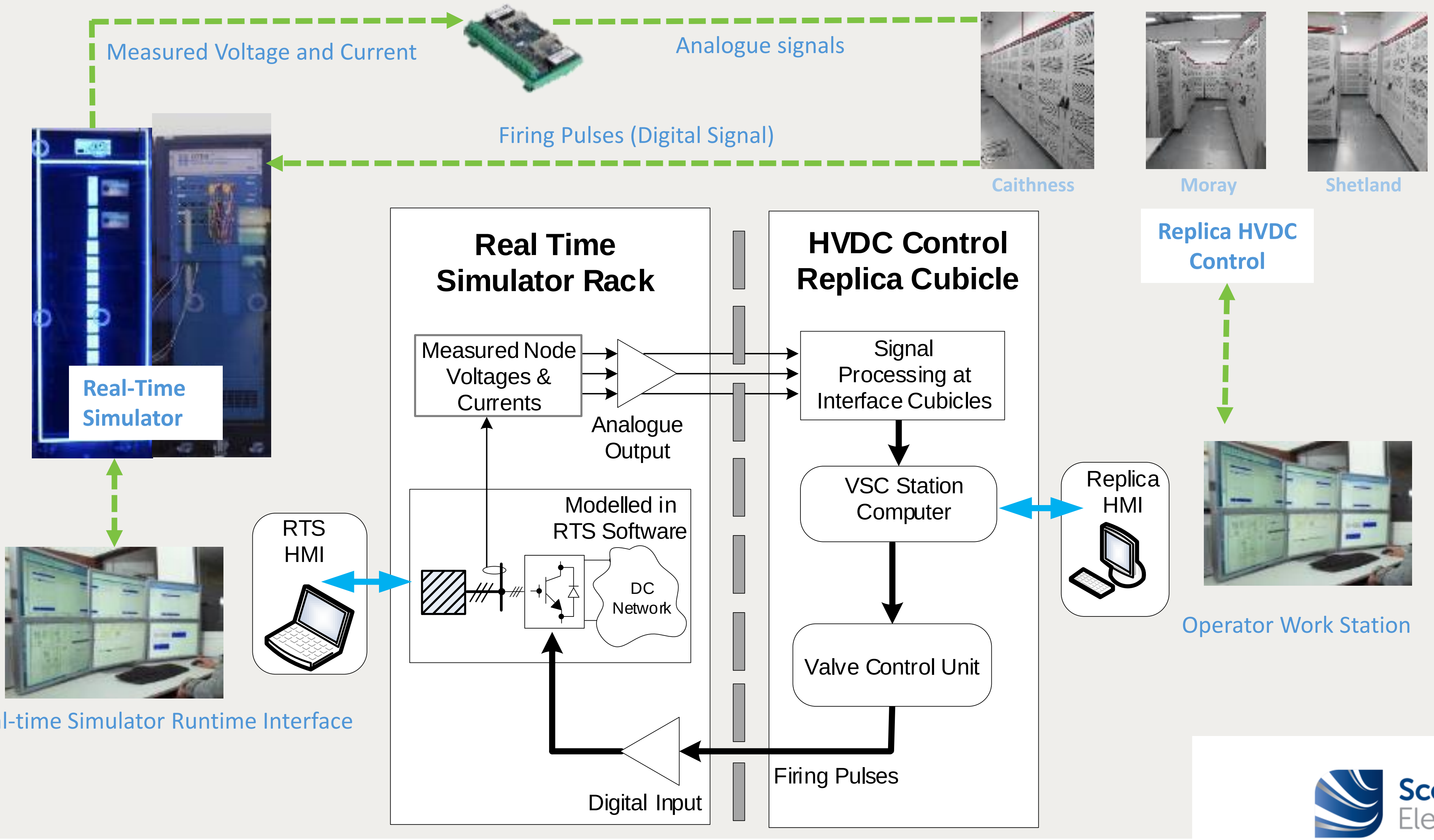
CMS – *Replica C&P Panels*



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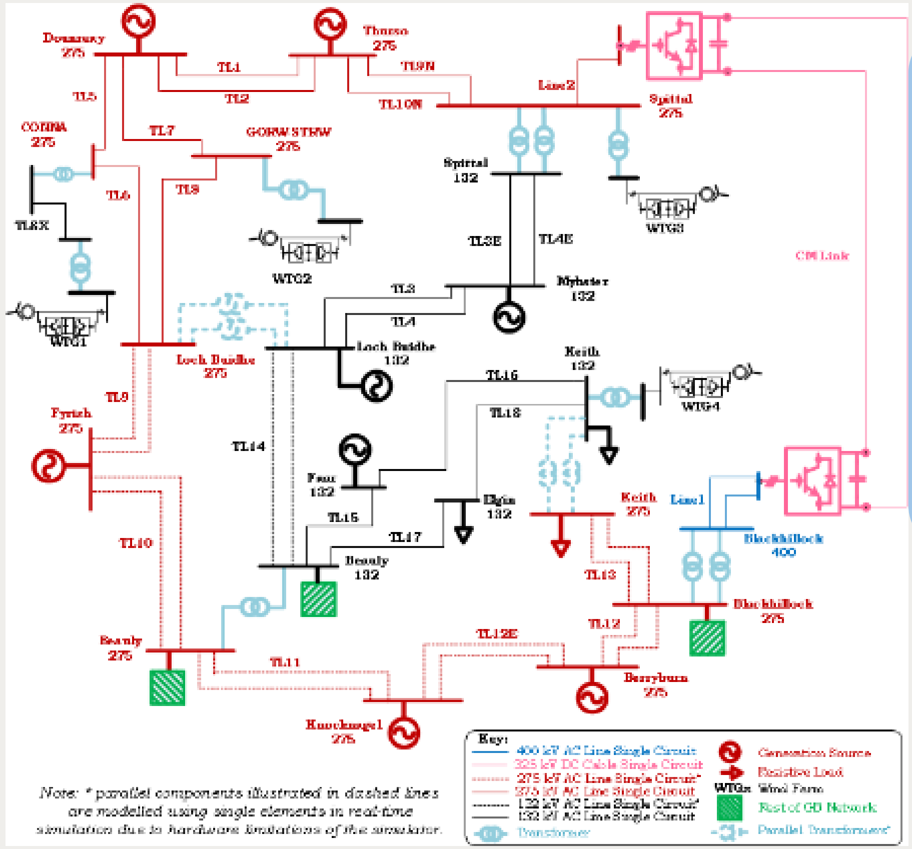
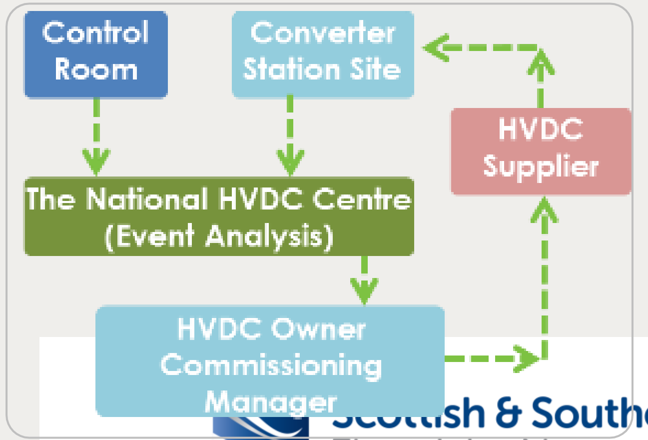
CMS – *Replica Applications*

- **Modelled** North of Scotland AC Network in Real-time Simulation.
- **Tested** response of Spittal converter station to AC faults on **275kV** & **132kV** circuits.
- **Demonstrated** effectiveness of extremely weak grid control at Spittal converter station.
- **Validated** emergency power control function for preventing voltage instability at Spittal.



Simplified North of Scotland Network Modelled using RTS

Operational Support
- In-House Training
- Respond to Network Changes
- Diagnose Faults/Alarms
- Testing Updates/ Upgrades
- o Long-term Model



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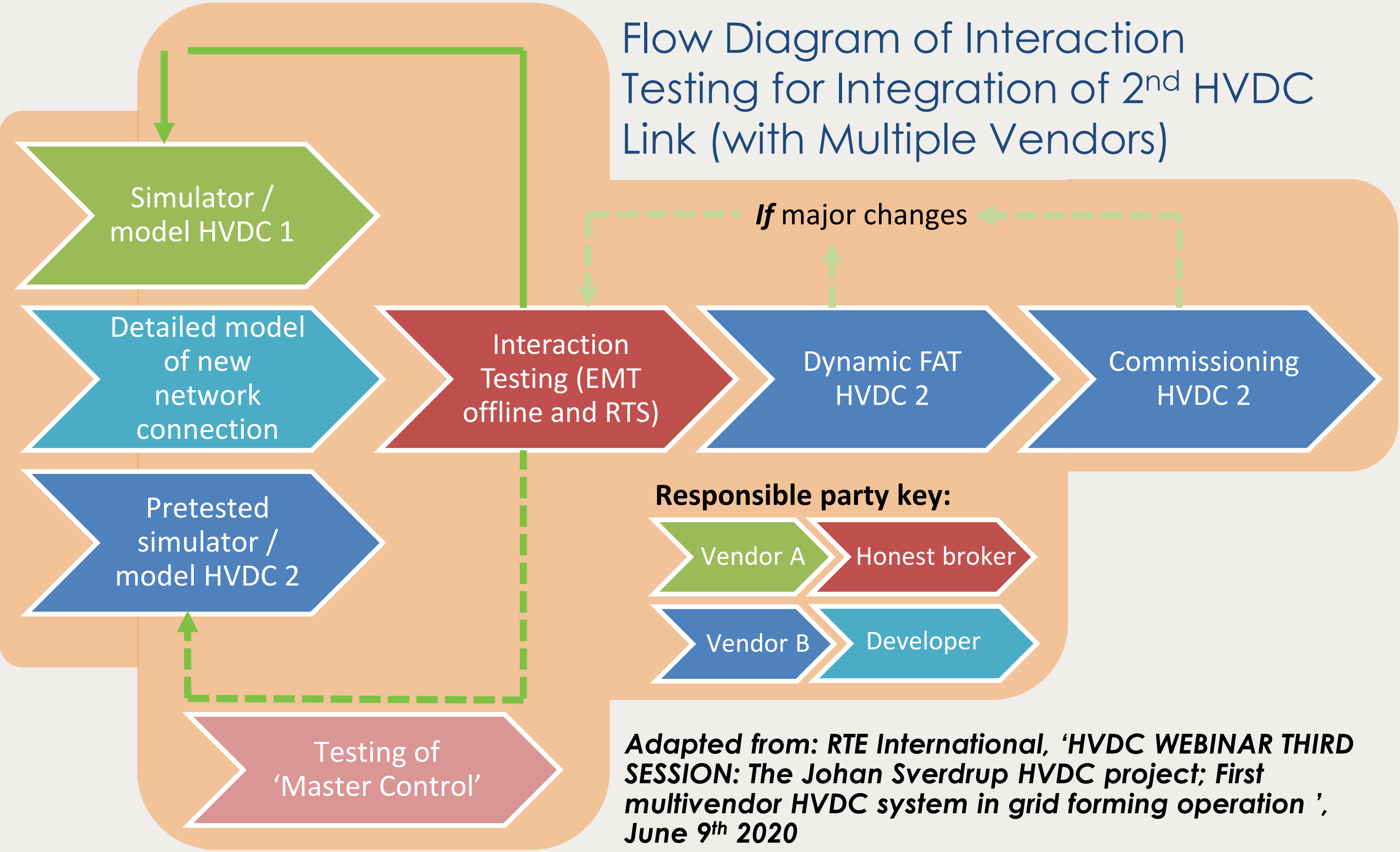
CMS – *Learnings*

- Upfront considered use of Replicas to:
  - De-risk multi-stage (potentially multi-vender) development
  - Facilitating multi-terminal solutions and interconnected DC hubs;
  - De-risking control interactions between converters connected in electrical proximity, and also with other fast acting power electronic controllers embedded within the ac network;
  - Training and developing Transmission Planning and Operations Engineers;
  - Undertaking post-commissioning scenario planning and network analysis

Flow Diagram of Interaction Testing for Integration of 2nd HVDC Link (with Multiple Vendors)



Adapted from: RTE International, 'HVDC WEBINAR THIRD SESSION: The Johan Sverdrup HVDC project; First multivendor HVDC system in grid forming operation ', June 9th 2020

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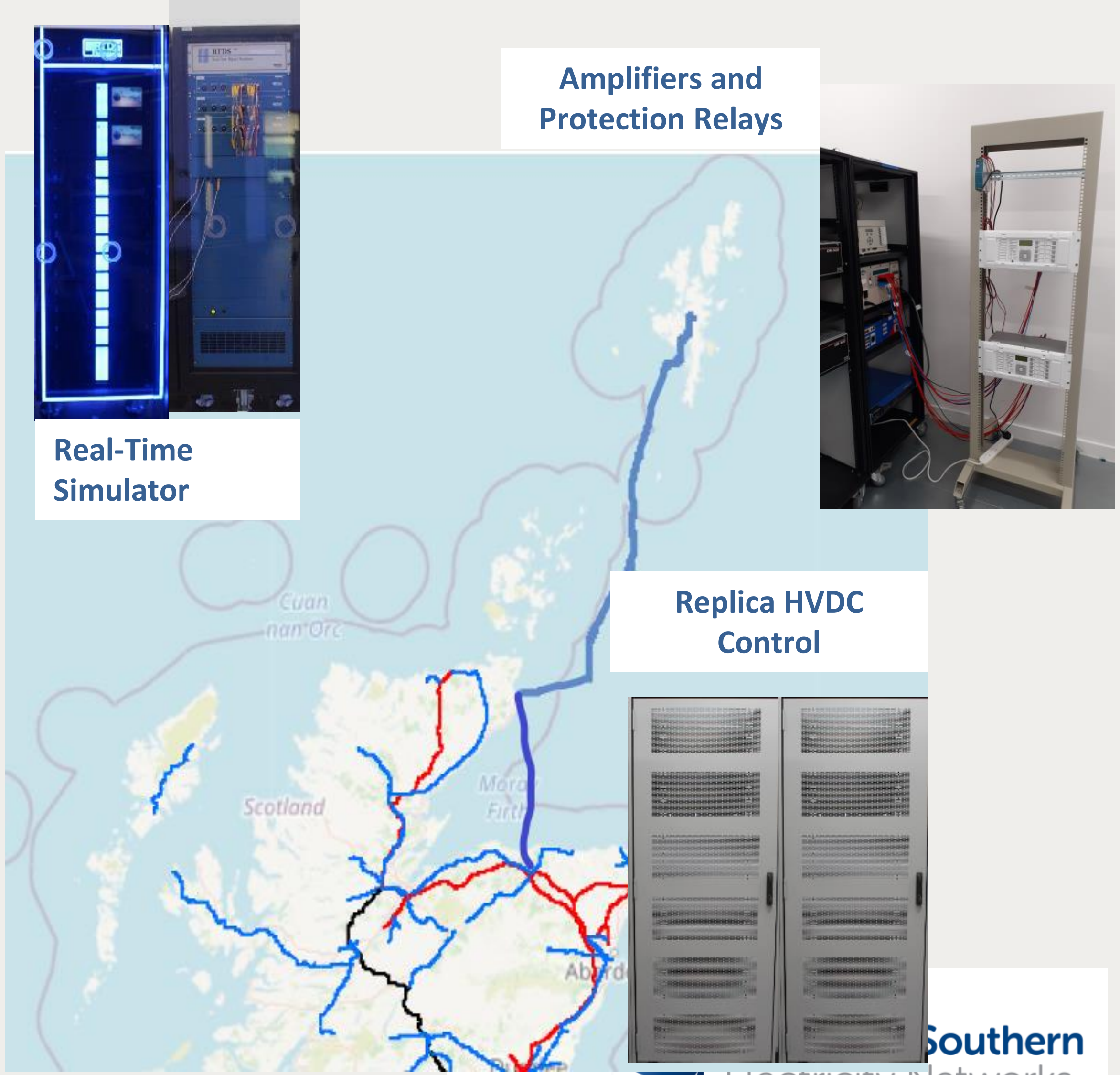
Shetland Low Fault Level Protection Testing

- **De-risk** the integration of new 132kV transmission line protection in the Shetland Island.
- **Model and Integrate** key components like the Island AC network, onshore AC network, CMS HVDC replica control and protection panels and AC protection relays.
- **Test** various internal and external faults and ensure the protection scheme provide optimal security to the new transmission circuits.
- **Recommendation –** Summarise the findings and provide recommendation to the project team based on the study results and findings.



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PROMOTioN

Progress on Meshed HVDC
Offshore Transmission Networks

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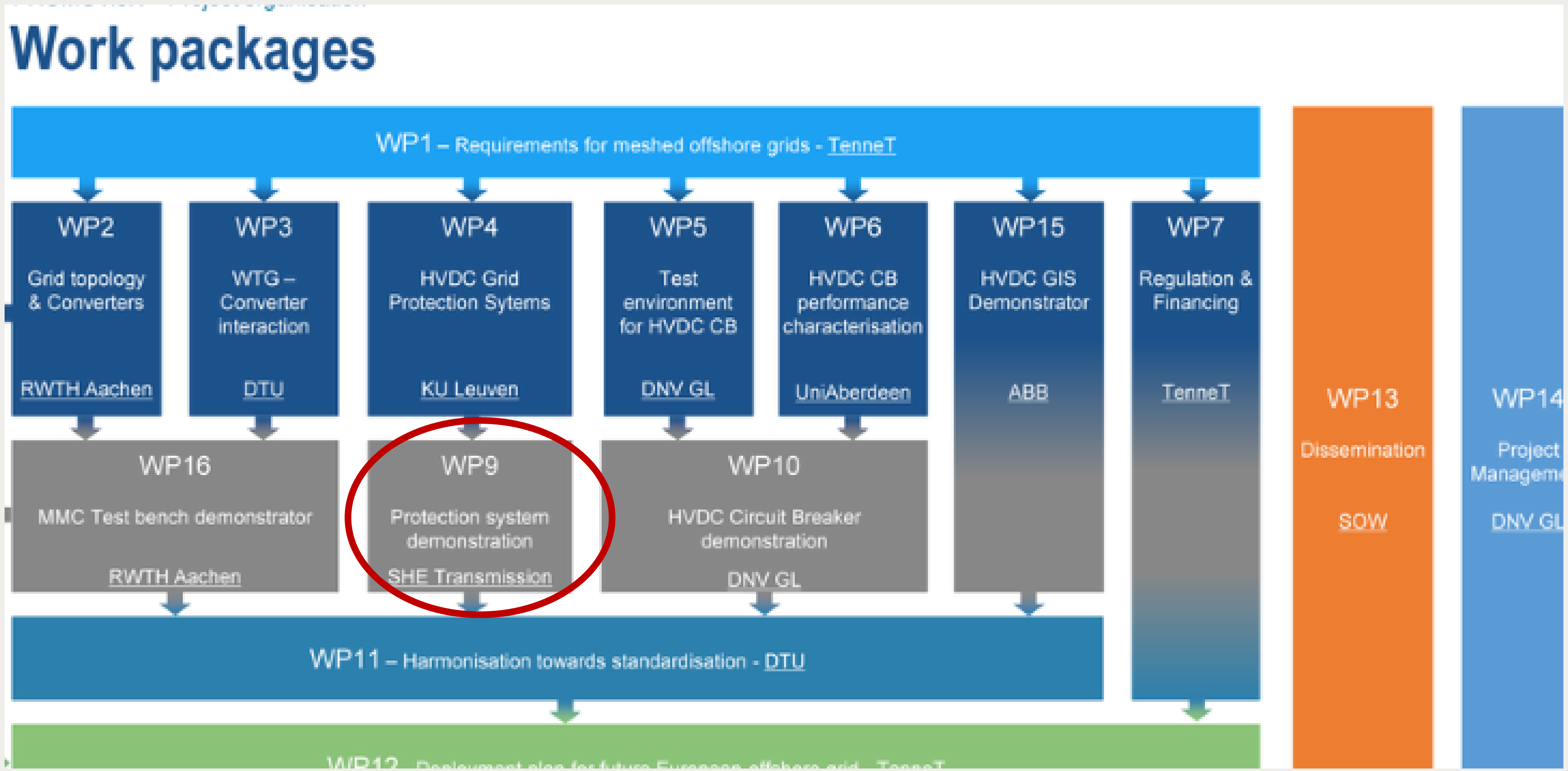
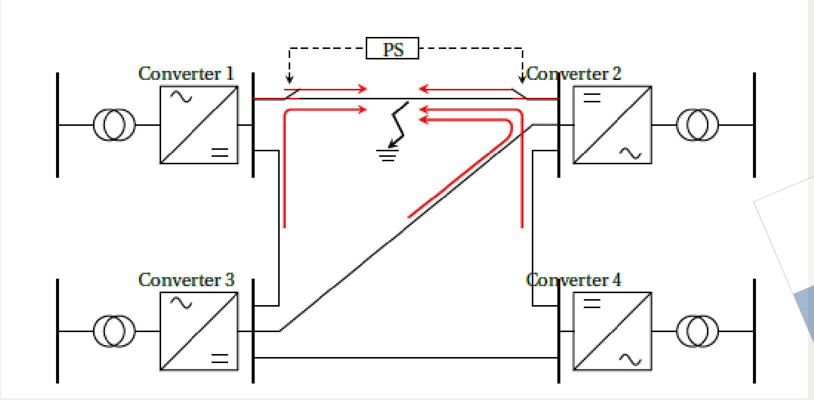
PROMOTioN – *Overview*

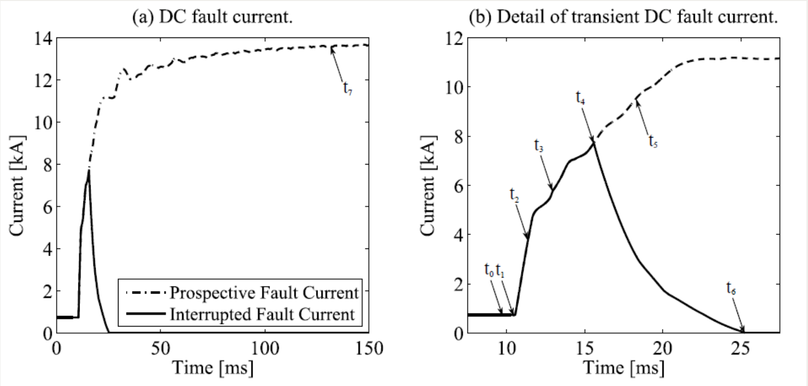
PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS



PROMOTioN – *DC Faults*

Fault Currents within a DC Grid





Fault current characteristics

- ❑ No zero crossings
- ❑ High rate-of-rise
- ❑ High steady state value

⟺ Sensitive (& expensive) converters and fast controls

Options for Protection

Converter AC breakers

- ❑As used in existing projects
- ❑Slow (40-60 ms opening time)
- ❑Not selective

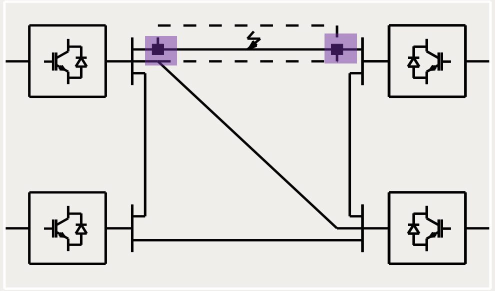
Fault-current blocking converters

- ❑Higher losses compared to half-bridge
- ❑Fast (responsive within a few ms)
- ❑Not selective

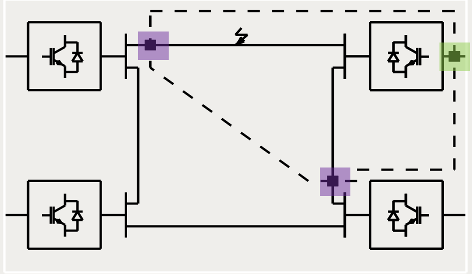
DC circuit breakers

- ❑Operating time of 2-10 ms
- ❑Trade-off in losses vs speed
- ❑Allows selective fault clearing

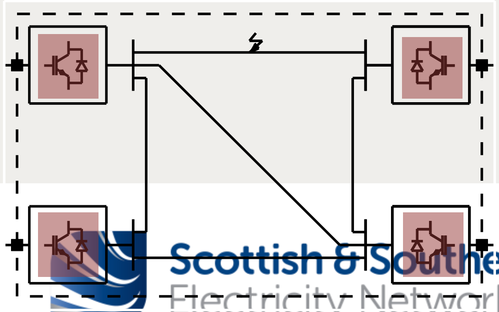
Selective: DCCBs on every line end



Partially selective: Split DC grid in sub-grids (protection zones)



Non-selective: Temporary shut down the whole DC grid



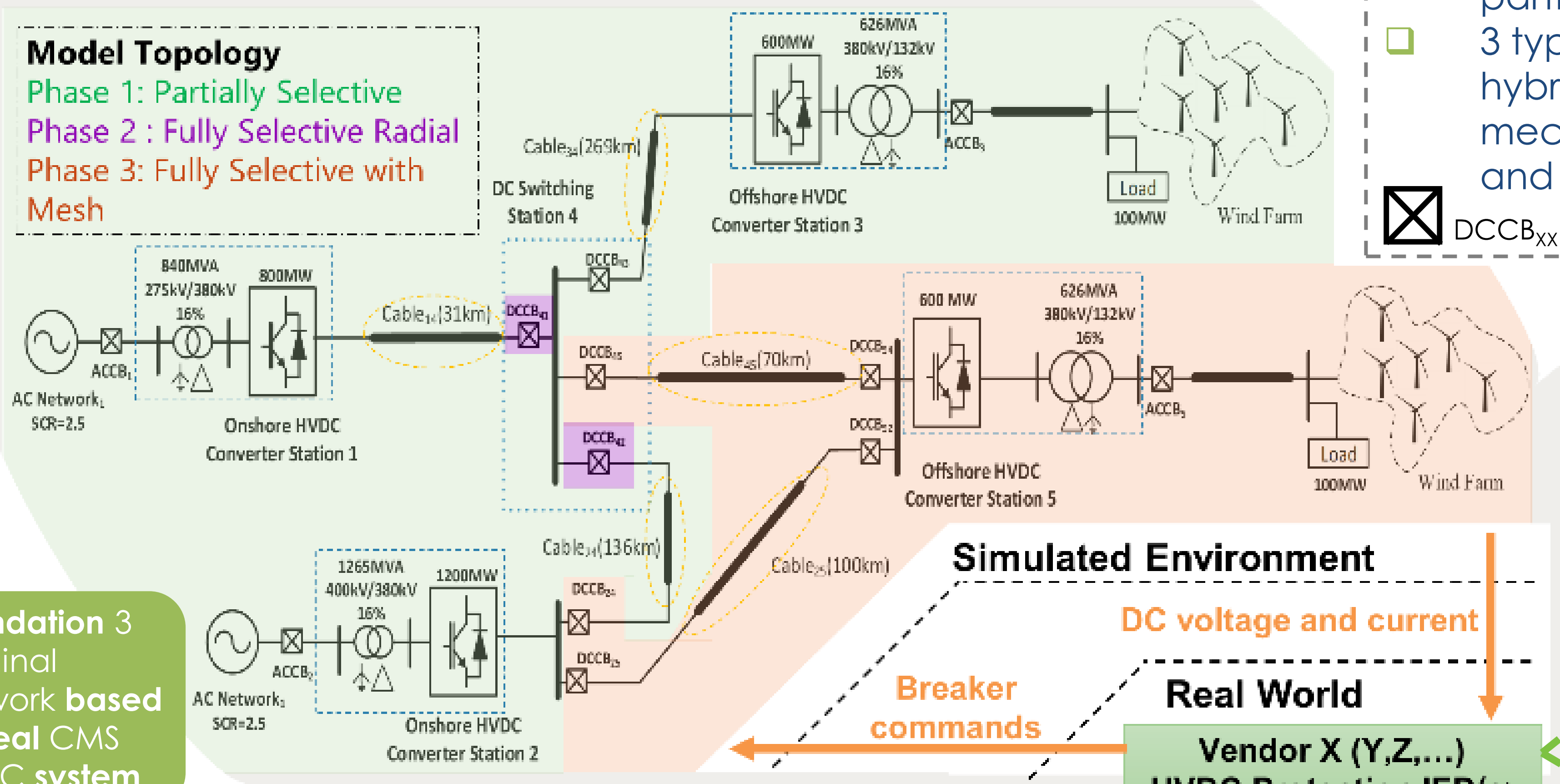
PROMOTioN – *DC Protection Testing*

HVDC Cables
- Parameters from real project
- Travelling wave frequency-dependent phase model used giving accurate v, i response

Converters
- Open-source
- Average HB-MMC
- Includes high and low level control

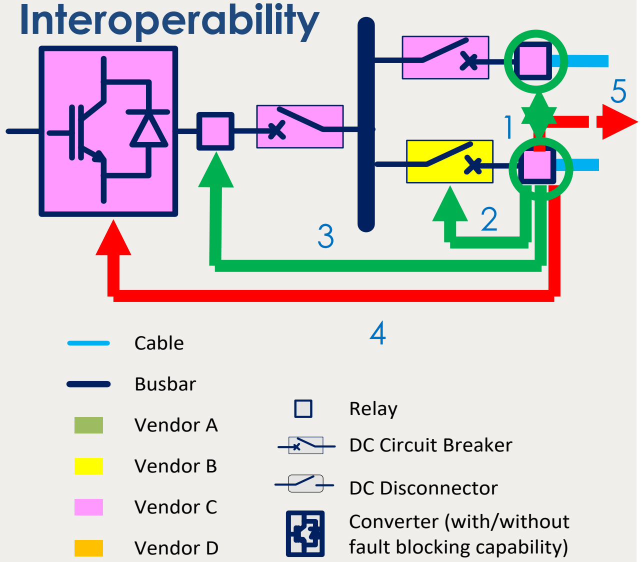
DCCBs
- Developed by WP6 in collaboration with industrial partners
- 3 types: hybrid; mechanical; and VARC

⊠ $DCCB_{XX}$



Foundation 3 terminal network **based on real** CMS HVDC **system**

Interoperability



Real time operation lets us **connect physical devices** in a **closed-loop** with the simulated environment
- Shows dynamic response of the system as test continues after action of the device.
- Test multiple devices simultaneously
- More detailed system representation than open-loop test provides

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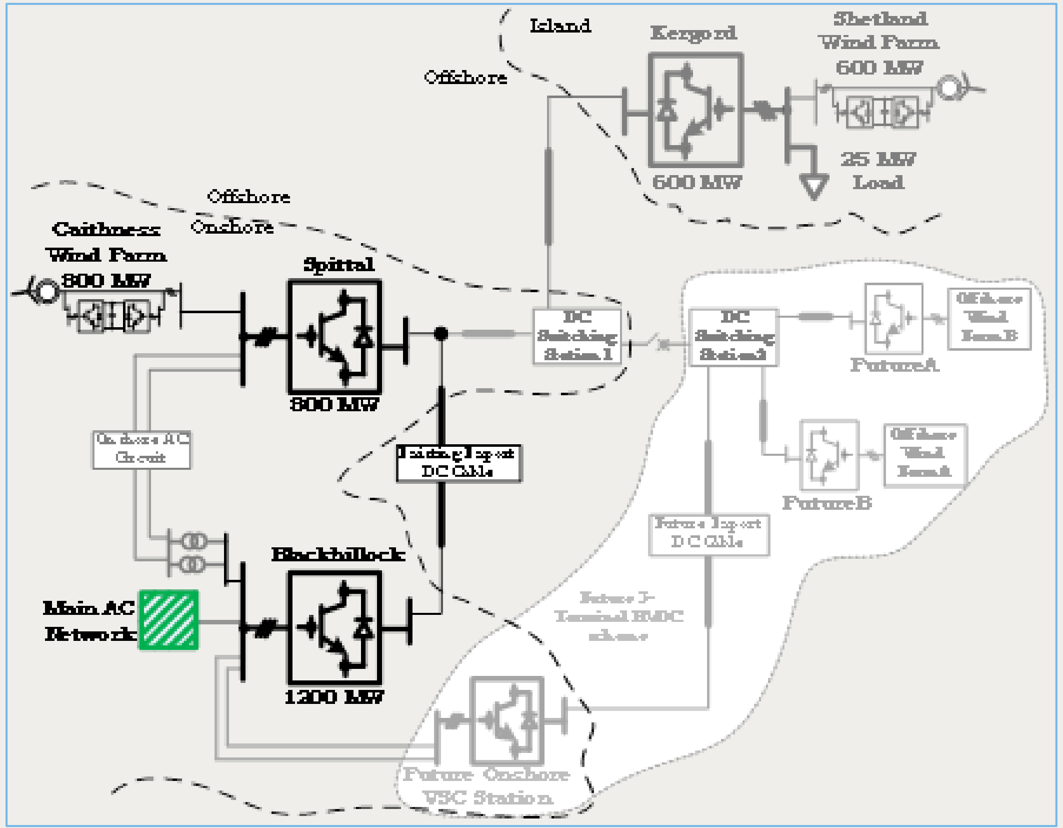
Multi-terminal Extension of VSC- HVDC Systems

Introduction

- VSC-HVDC technologies are suitable for connecting relatively weak AC systems into stronger grid areas/ external grids.
- VSC has improved control capabilities
- Multi-terminal VSC systems have greater flexibility and can change power flow direction provided one end maintains the voltage polarity.
- This presentation identifies that multi-terminal extension of VSC-HVDC system is technically feasible, outlines co-simulation options and testing requirements with project risks to be managed.



CMS Multi-terminal HVDC Design

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Multi-vendor de-risking

How to address interoperability

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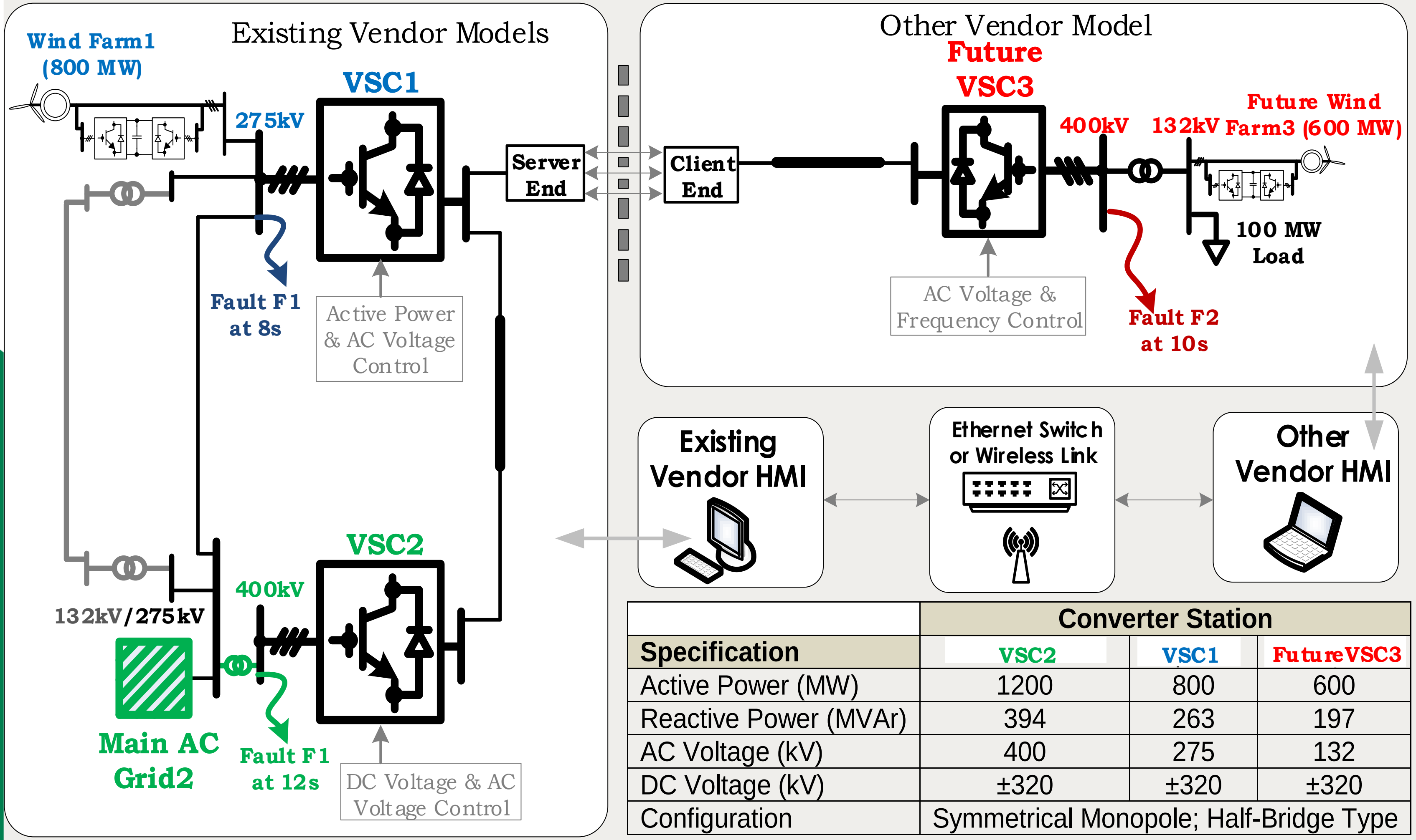
Co-simulation of Multi-Vendor VSC- HVDC Systems

3-terminal HVDC System Control and Test Cases



Specification	Converter Station		
	VSC2	VSC1	FutureVSC3
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		

- Control Modes:
  - **VSC1** regulates active power and reactive power.
  - **VSC2** controls DC voltage for power balancing and regulates reactive power.
  - **VSC3** creates offshore AC voltage with fixed frequency, magnitude and phase angle.

- Test cases:
  - 0.2p.u. active power ramp on **VSC3** at 2.5s and 4.5s.
  - 0.4p.u. active power ramp on **VSC1** at 5.5s; and
  - 100ms 3-phase to ground AC faults on **VSC1** at 8s, **VSC3** at 10s and **VSC2** at 12s.

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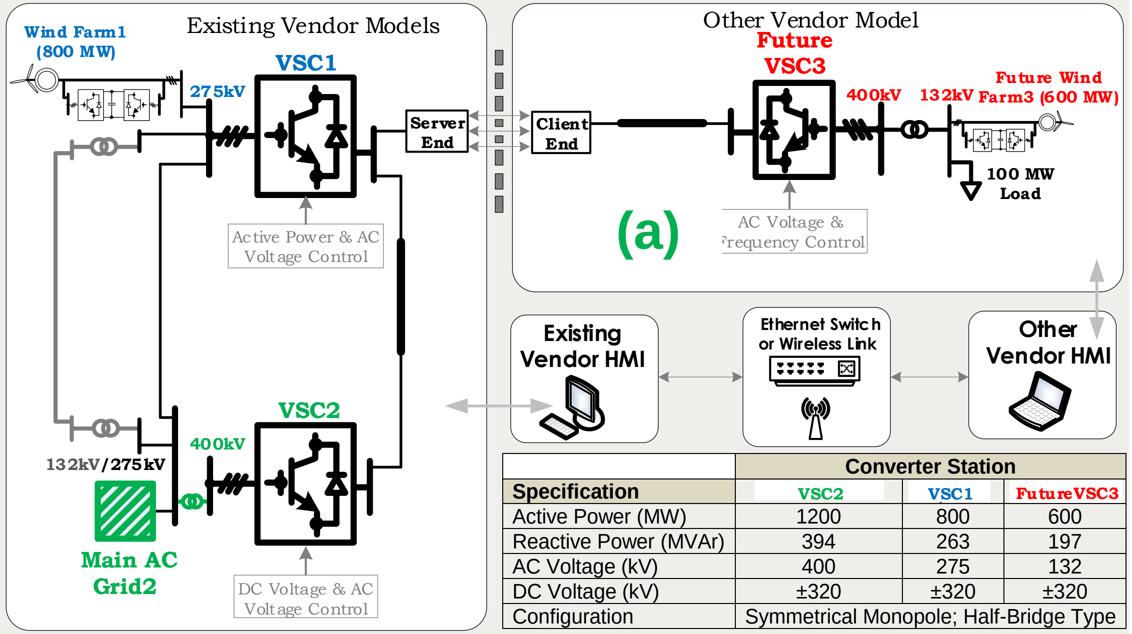
Co-simulation of Multi-Vendor VSC- HVDC Systems

Dynamic Performance Studies (DPS)

- To verify off-site performance of HVDC control and protection (C&P) systems in EMT-type software models prior to site delivery.
- Future VSC terminal DPS supplied by different vendor, would require co-simulation of EMT-type offline models from different suppliers.
- The Johan Sverdrup HVDC project in Norway represents a type of multi-vendor VSC scheme.
- An example 3-terminal HVDC system with 2 existing VSCs and a future terminal by another vendor, co-simulated using an offline EMT tool.

- Co-simulation can preserve IP arrangements of HVDC C&P systems from different manufacturers.



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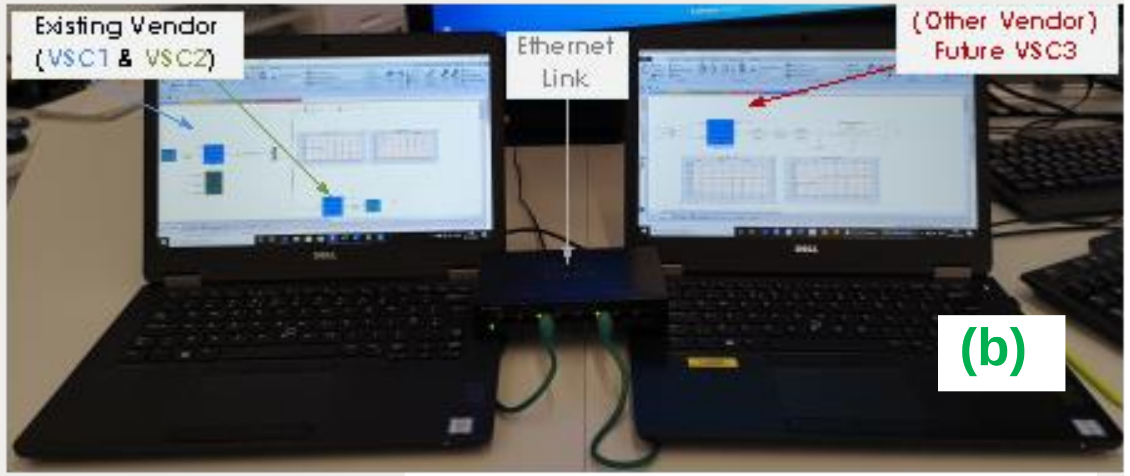

Co-simulation of 3-terminal HVDC Scheme

(a) Schematic (b) Set-up

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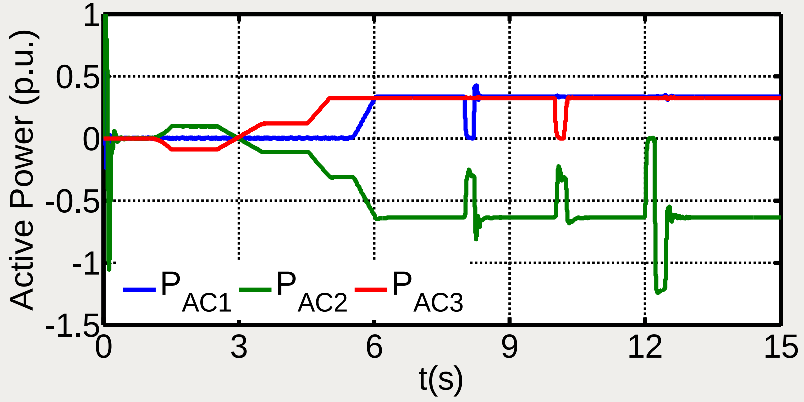
Co-simulation of Multi-Vendor VSC- HVDC Systems

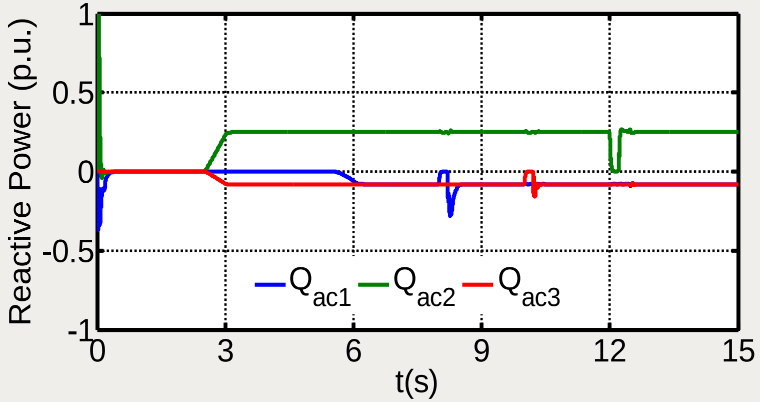
DPS Results and Discussions – Offline Co-simulation

- The co-simulated 3-Terminal HVDC system is stable across the test cases investigated

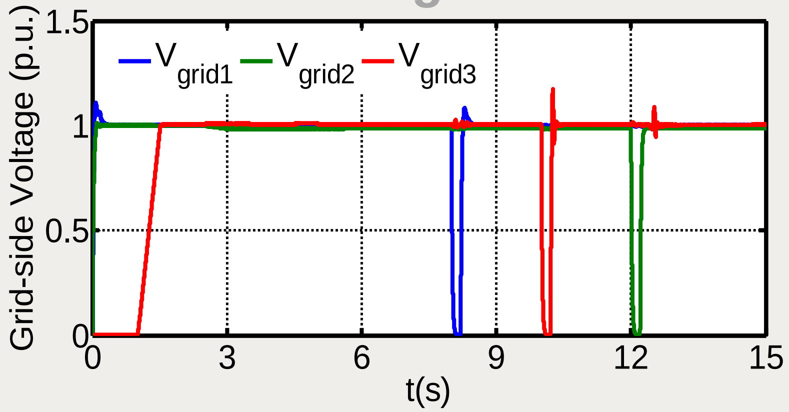
- Active Power



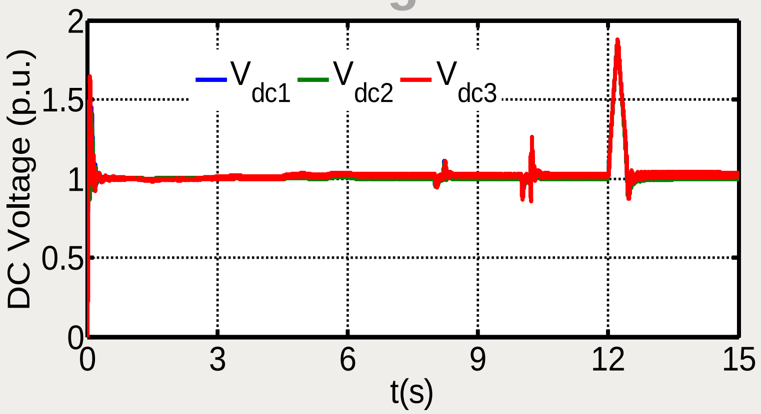
- Reactive Power



- AC Voltage



- DC Voltage



- 1.8p.u. DC overvoltage observed for AC fault on inverter terminal VSC2 at 12s, and the system recovers within 500ms.
- DC choppers, fast adaptive HVDC droop control or power reduction schemes can be used to prevent DC overvoltage.
- Ethernet link between two separate computers minimised telecommunication delays compared to wireless option

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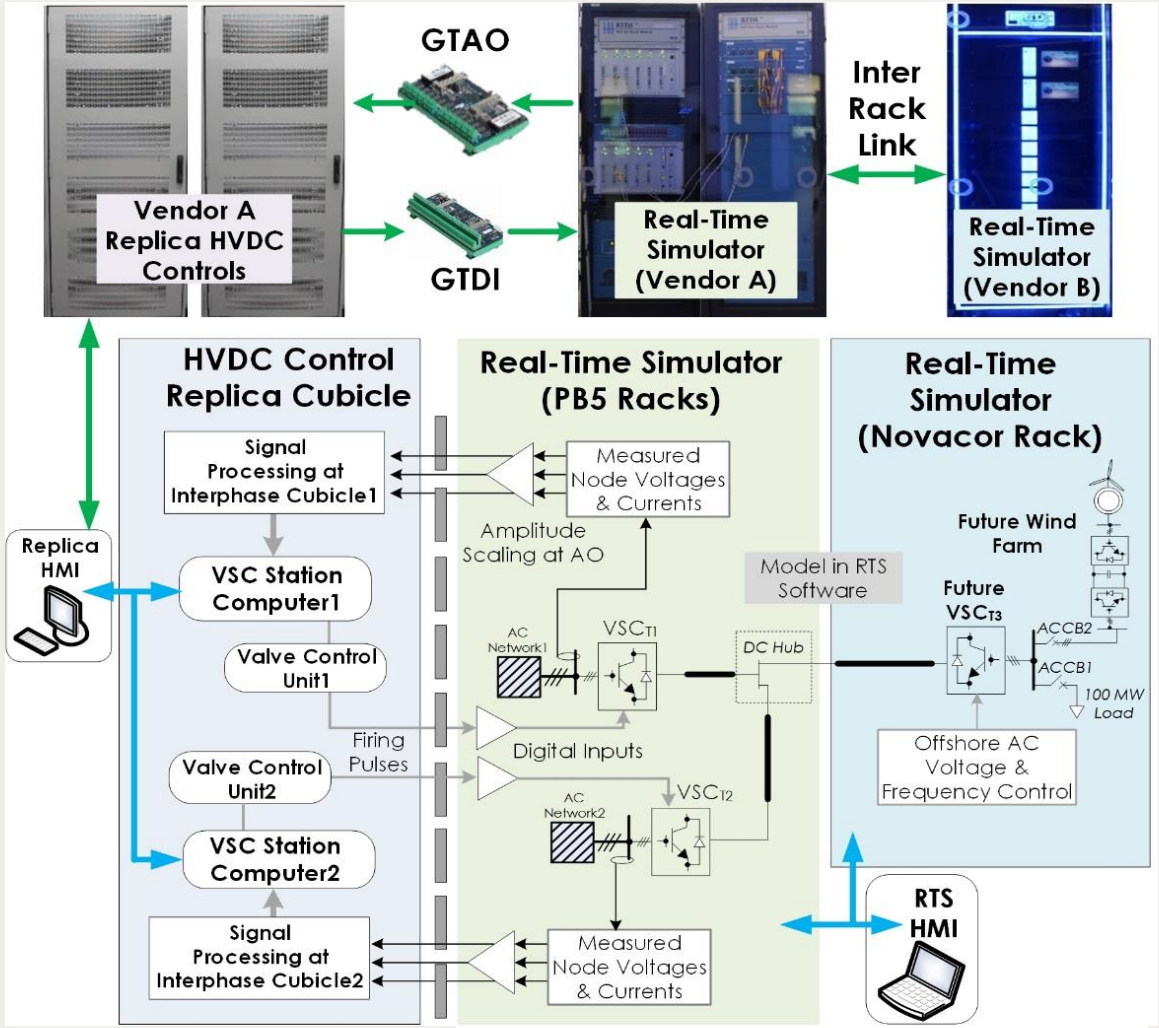
Testing VSC-HVDC Supplied by Different Manufacturers

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.

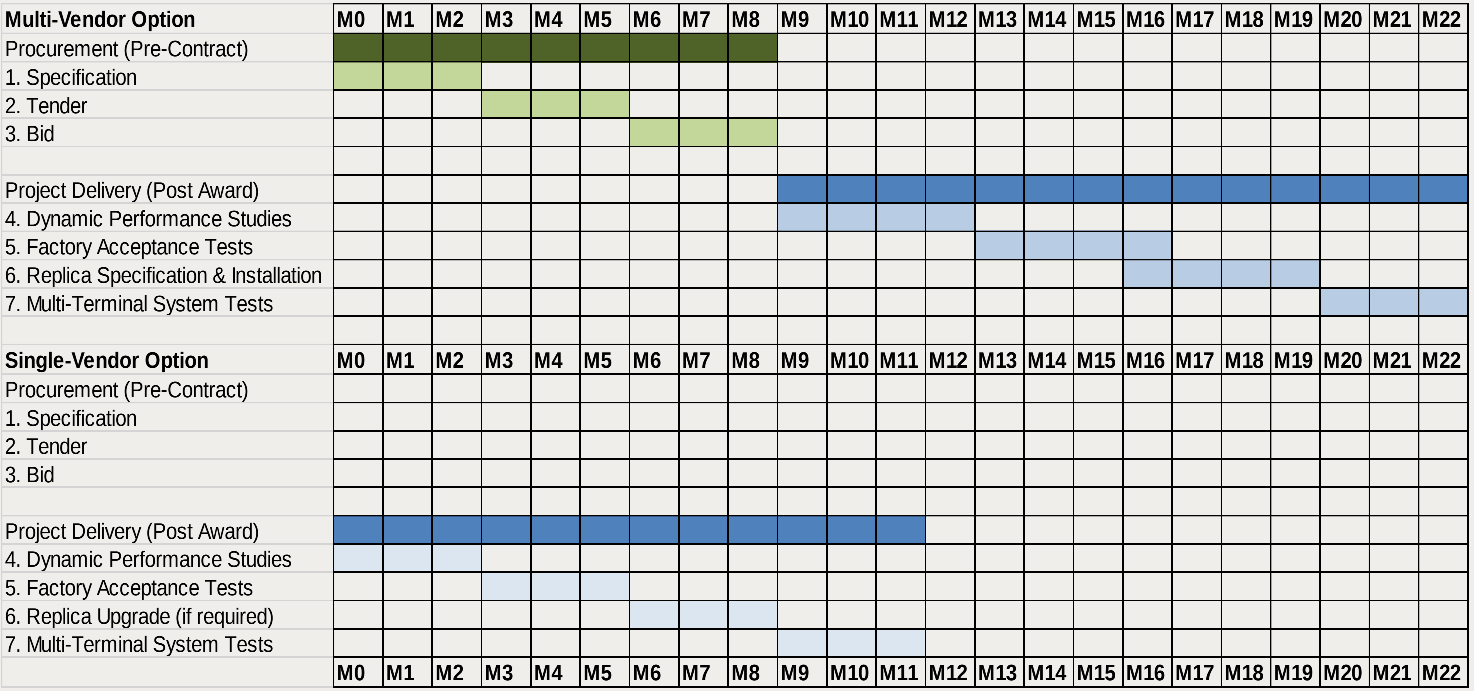


Hardware in the loop set-up

Key Considerations and Project Risks

Role of independent test environment in multi-vendor HVDC schemes

- Additional time up to 12 months may need to be manage for multi-vendor option compared to a single-vendor approach, mainly due to multi-vendor testing requirement.



Estimated Project timeline for additional HVDC terminal

- **Key considerations include:**
  - **Model Sharing:** manufacturers will need to shared detailed EMT-models, fit for intended purpose
  - **Replica C&P system:** future HVDC supplier must provide a replica C&P test for multi-vendor tests to track changes in development and or further changes in service.
  - **Procurement:** multi-vendor tests may result in dis-interest from other suppliers
  - **HVDC Grid Code:** standardisation of C&P specifications will reduce interoperability risk.

- **Vendor responsibility has to be assigned and better coordination between different vendors could streamline development timeframes.**

Summary

Multi-terminal extension of VSC-HVDC system is technically feasible

- No major technical barriers to multi-vendor systems with converters provided by different suppliers;
- Dynamic performance studies (DPS) can be performed using EMT-type tools with co-simulation capabilities to de-risk HVDC schemes involving different vendors ;
- Factory acceptance testing (FAT) of HVDC C&P systems of converter terminals being supplied by different equipment manufacturer can be performed at independent testing environment to demonstrate compatibility with replicas of existing HVDC scheme; and
- Multi-vendor HVDC option would incur an additional time (estimated as 12 months), but coordination of multi-vendor testing could streamline development timescales.

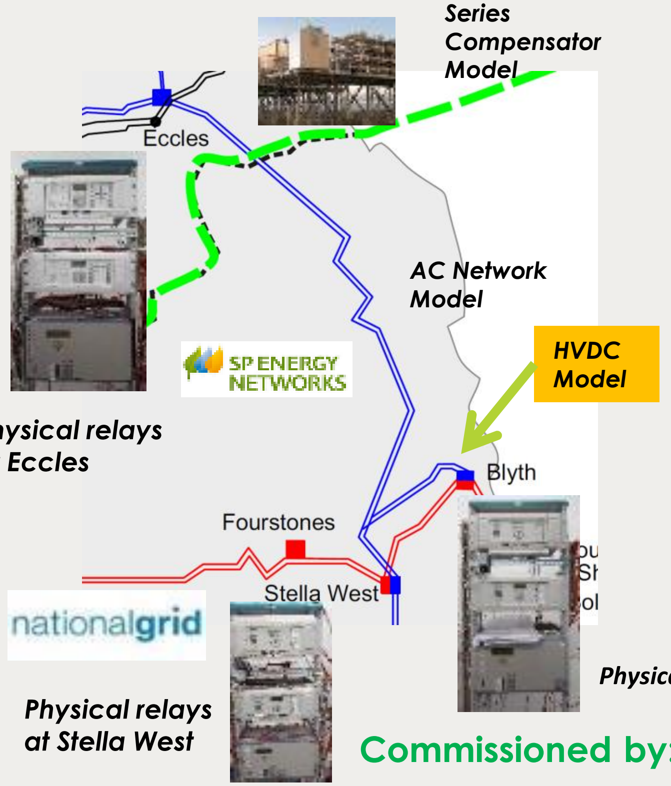
Protection de-risking

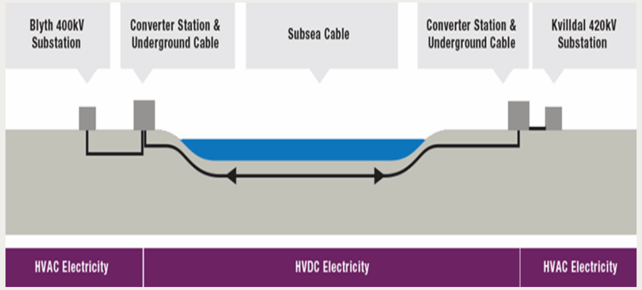
How to ensure reliability and resilience

Use of RTS for De-risking Innovation Projects

Impact on AC Protection – New HVDC Connection

NGET and SPEN commissioned the HVDC Centre to test & validate AC protection performance and co-ordination testing for a new HVDC interconnector to ensure the security and resilience of the GB electricity network.





Source: http://northsealink.com/

- Capacity to transmit 1,400 MW of power at DC voltage ±525kV
- 730 kilometre link will be the world's longest subsea power interconnection

The protection study has increased our understanding of the:

- Potential risks associated with AC protection in the presence of HVDC links & FACTs
- Practicalities of implementing multivendor protection system testing within GB Network
- Differences between modelled and actual protection behaviour.

Commissioned by: nationalgrid & SP ENERGY NETWORKS

Overview of Eccles-Blyth-Stella West 400kV Protection Performance Studies

A test setup with Physical relays at our centre

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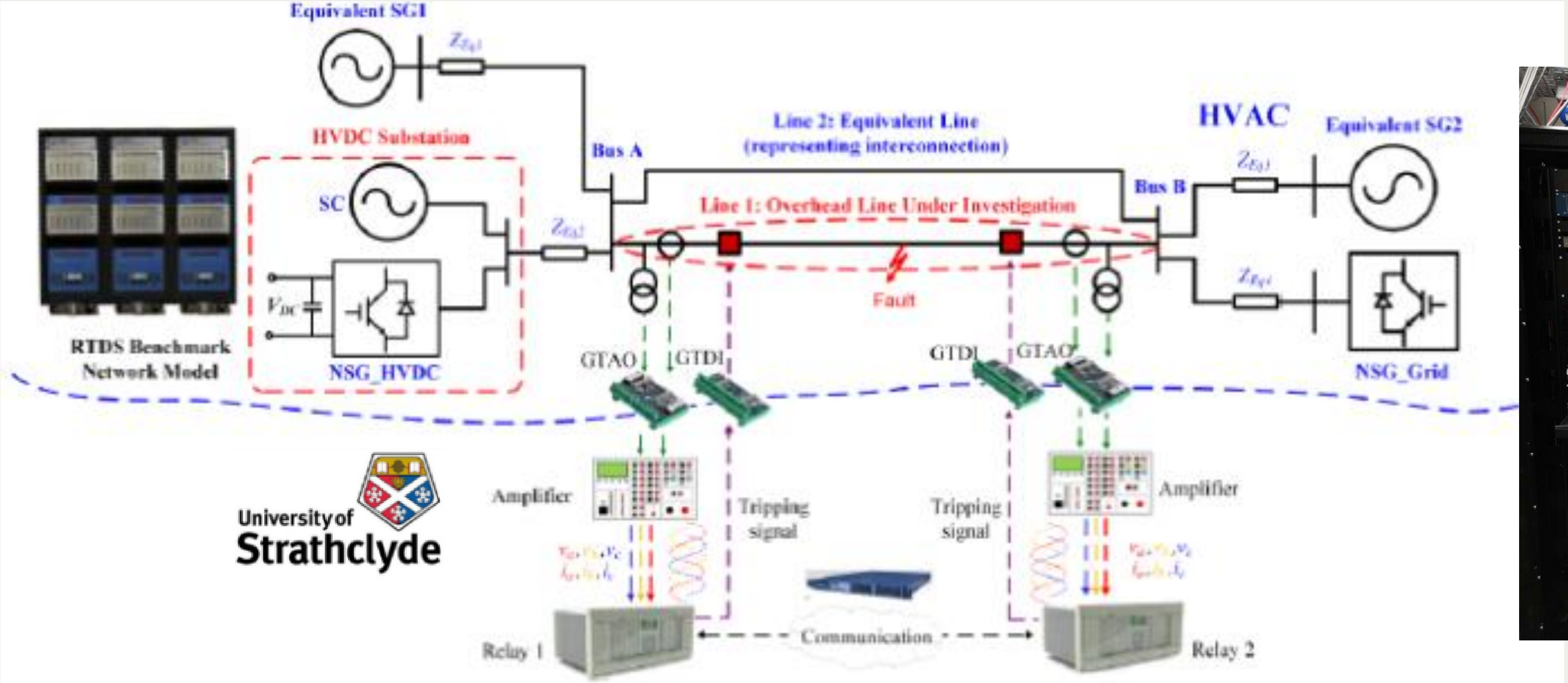
The National HVDC Centre

Use of RTS for De-risking Innovation Projects

Impact on AC Protection – Evaluation of the Impact of HVDC Systems with Synchronous Condensers on AC Protection



- A simplified but representative RTDS network model
- A laboratory test configuration and procedures using RTDS HiL-setup for AC protection testing
- Recommendations of the desirable control strategies for:
  - HVDC systems
  - most desirable sizing of SC for HVDC systems during faults to support the AC protection

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R&D

Driving new tools, approaches & insights to de risking

The National HVDC Centre

Use of RTS for De-risking Innovation Projects - *Innovation Projects*

Older Completed Innovation Projects

Developing Open-Source Converter Models

University of Strathclyde

Stability assessment for co-located converters

MANCHESTER 1824 The University of Manchester

Design of DC/DC Converter

University of Aberdeen

2019/20 Completed Innovation Projects

Coordination of AC network protection during HVDC energization

EPRI Electric Power Research Institute

Stability assessment and mitigation converter interactions

University of Strathclyde

Improving Grid Code for HVDC schemes

Cardiff University Prifysgol Caerdydd

2020/21 Ongoing Innovation Projects

Protection Performance and Validation in Low Strength Areas

Manitoba Hydro International

HVDC with synchronous condenser impact on AC protection

University of Strathclyde

Adaptive Damping of Power Oscillations using HVDC

EPRI Electric Power Research Institute

NIA Project

COMPOSITE Testing of HVDC-connected Wind Farms

Rte

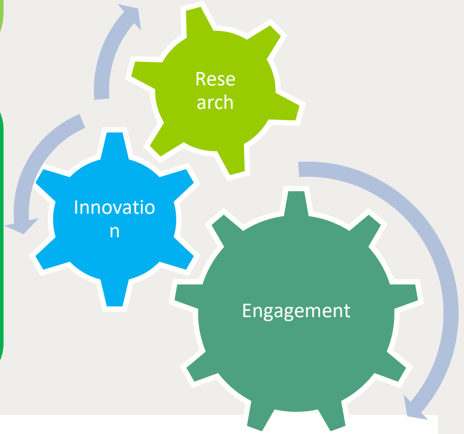
nationalgridESO

SP Energy Networks

nationalgrid

Scottish & Southern Electricity Networks

The National HVDC Centre



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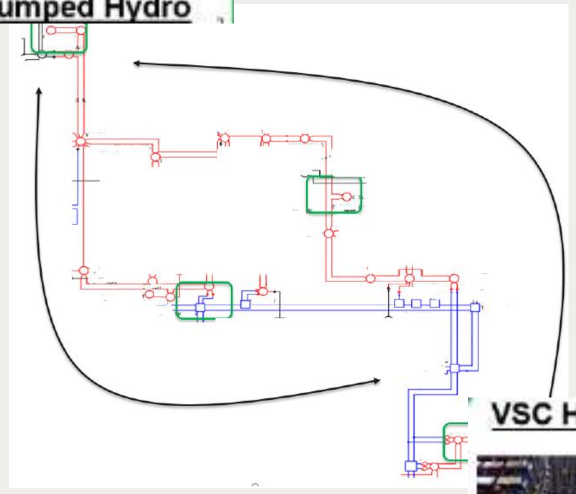
Transmission

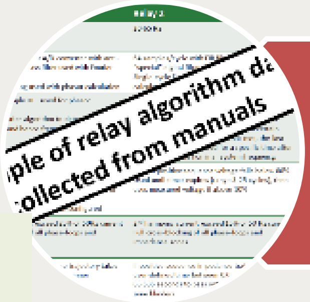
Use of RTS for De-risking Innovation Projects

Impact on AC Protection – HVDC to Black Start

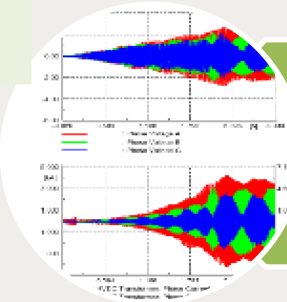
EPRI | ELECTRIC POWER RESEARCH INSTITUT

Real world example case used





Review algorithms of protection relays on the network



Use PowerFactory simulations to perform restoration studies

Hardware testing of specific relays in HVDC Centre

- Risk of resonance during hard-energisation
  - Existing protection may not trip in response to the resonances
  - Relying on HVDC to detect and trip unless mitigation implemented
- Soft-energisation
  - Delayed fault clearance likely
  - Risk of exciting resonance due to fast post-fault voltage recovery
- Strategic reconnecting of load required to maximise grid stability
- VSC-HVDC provided sufficient current for fault detection/relay operation
- Weak grid issues exist which could complicate connection of wind farms

Use of RTS for De-risking Innovation Projects

Impact on AC Protection – HVDC to Black Start

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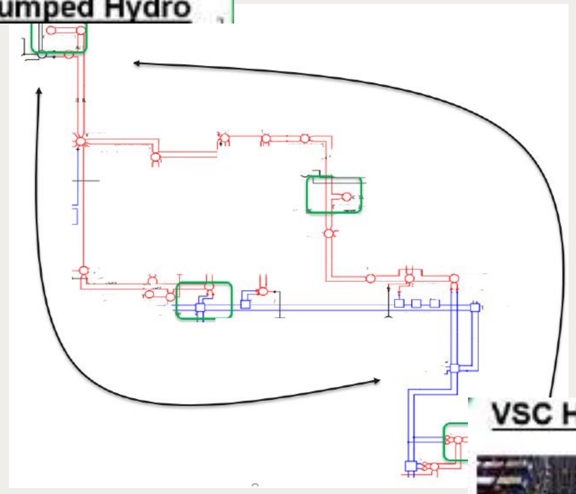

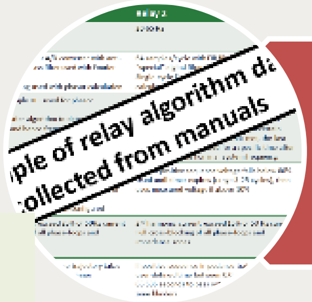

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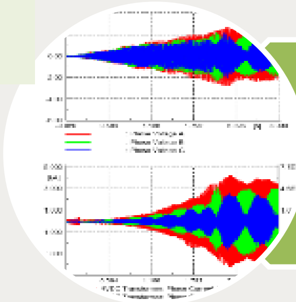

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The National HVDC Centre

Use of RTS for De-risking Innovation Projects

HVDC Converter Modelling– Phase I Converter and GB Network Modelling

Open-source converter model: Researchers at Strathclyde University together with The National HVDC Centre have developed and tested open-access different MMC topologies to provide building blocks for HVDC system studies.

Converter Modelling

- Open source Converter Model
- Converter topologies-HB, FB and Hybrid MMC
- Averaged, Detailed and Switching Function-MMC

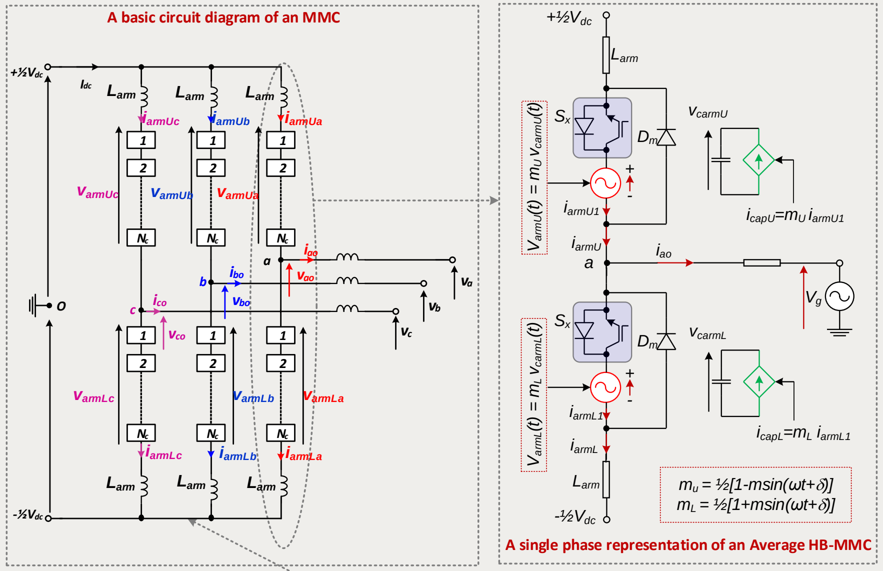
Converter Control Design

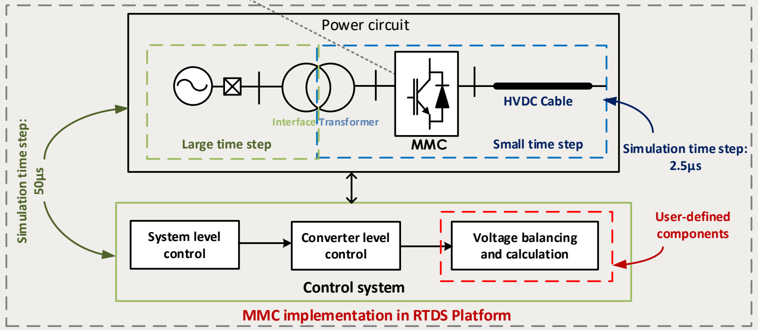
- High level Control
- Low level control

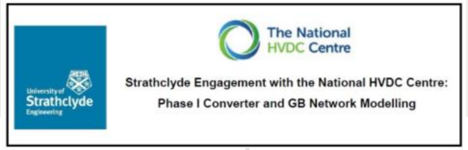
Real-time Implementation

- Small-time step
- Large-time step
- Interface

- Models include all necessary controllers to ensure correct operation
- The MMC models have also been used as the building block for modelling HVDC grid
- The offline (PSCAD) and real-time (RSCAD) models with associated technical reports and publications are available to download.







https://www.hvdccentre.com/open-source-converters/

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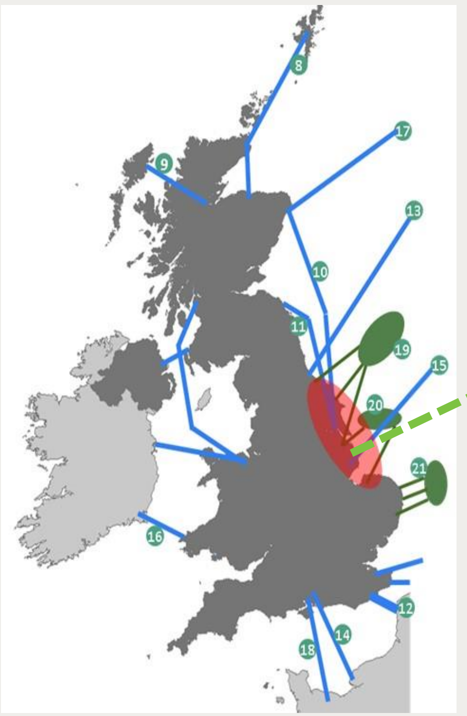
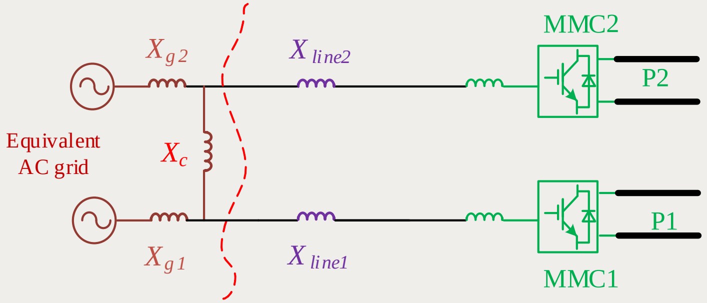
Use of RTS for De-risking Innovation Projects

Stability Assessment- Converter Interaction and Network Stability with High Converter Penetration

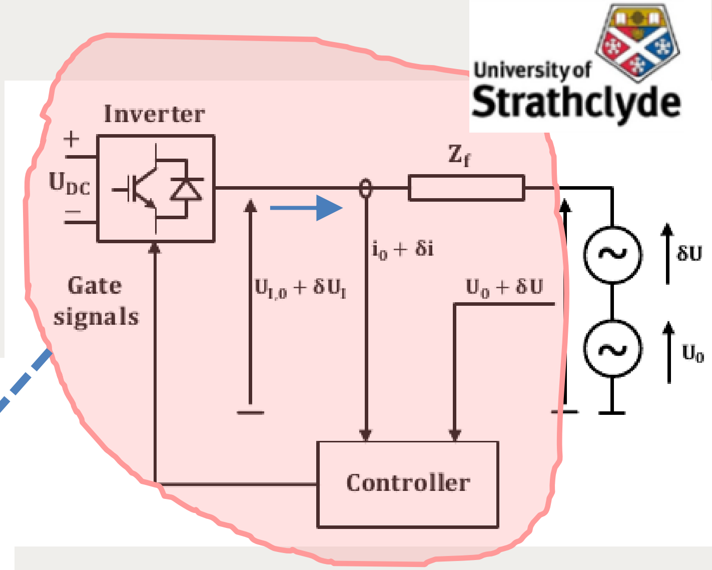
This project has focused on MMC impedance modelling and validation

- Need for adequate modelling method due to the existence of internal harmonics in MMC, e.g. the use of the harmonic state space (HSS) method.
- Stability analysis in frequency domain using impedance method
- Stability of multi-infeed converter system

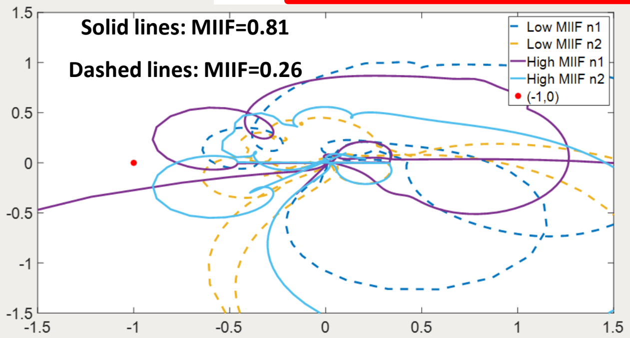


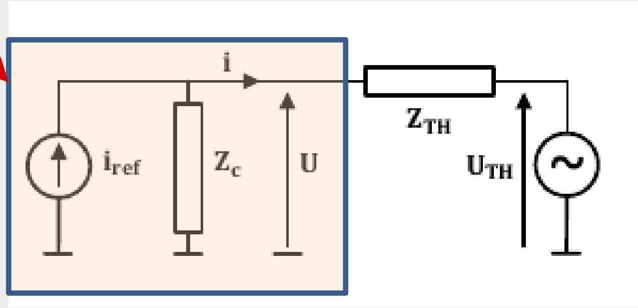


$$MIIF_{j,i} = \frac{\Delta V_i}{\Delta V_j}$$



$$Y_C(s) = -\frac{\delta i(s)}{\delta U(s)}$$





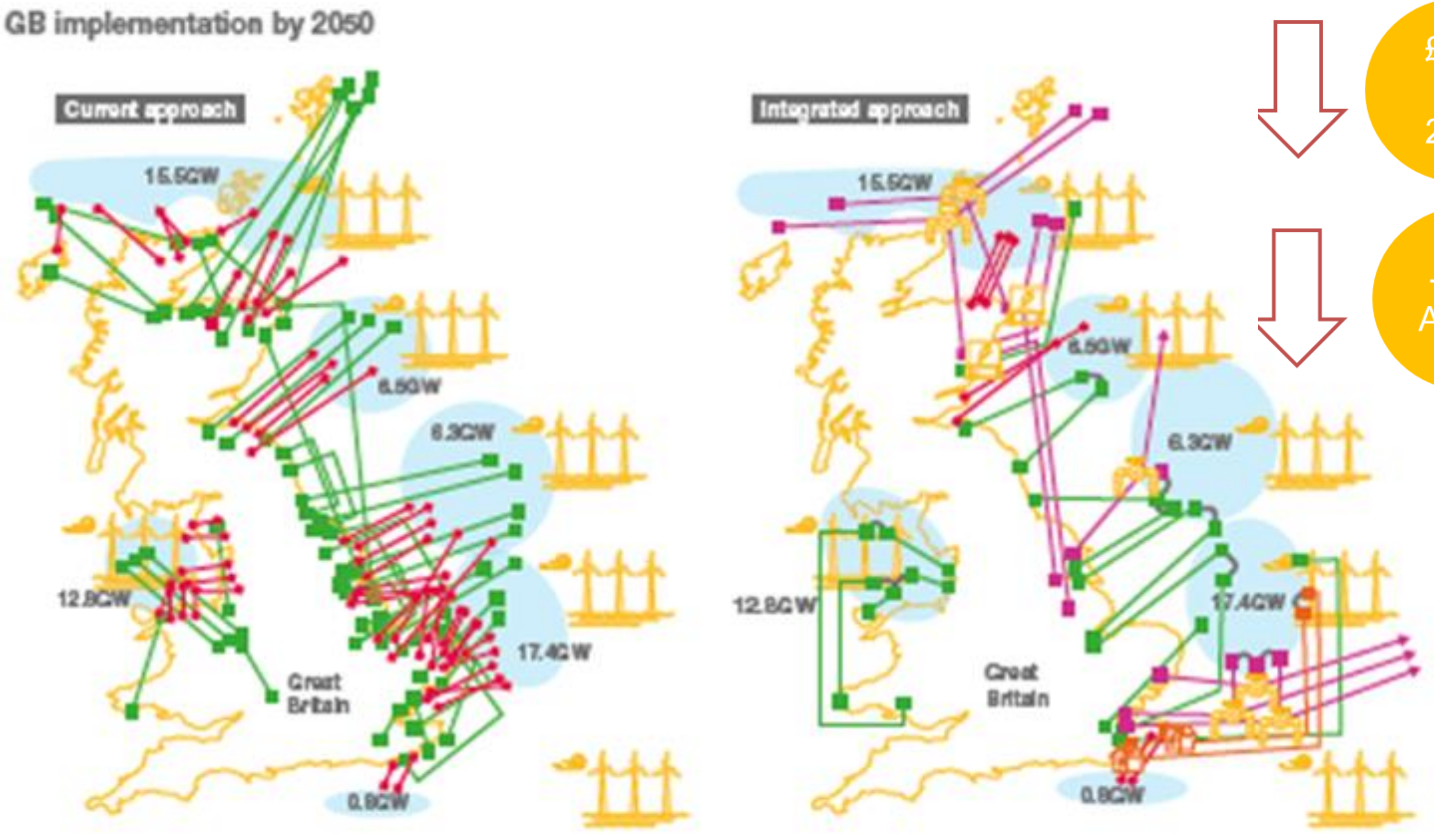
- To measure the interactions among multiple HVDC converters, the multi-infeed impact factor (MIIF), is used to categorize the network
- Preliminary study indicates that multiple converters in close electrical proximity (in frequency domain) can significantly affect system stability

Co-ordinated Offshore HVDC

Spearheading GBs'
Green transition…

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"*

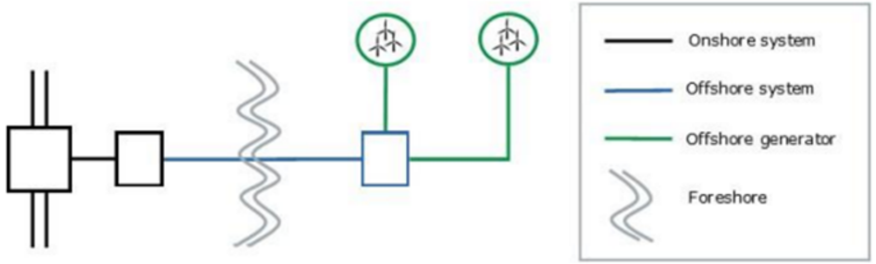
"We recognise the role the Centre plays in supporting the decarbonisation and net-zero targets, as HVDC transmission is recognised as an efficient method (less transmission losses) for the transfer of power over long distances, therefore making it relevant to the transmission of offshore renewable energy."

The National HVDC Centre

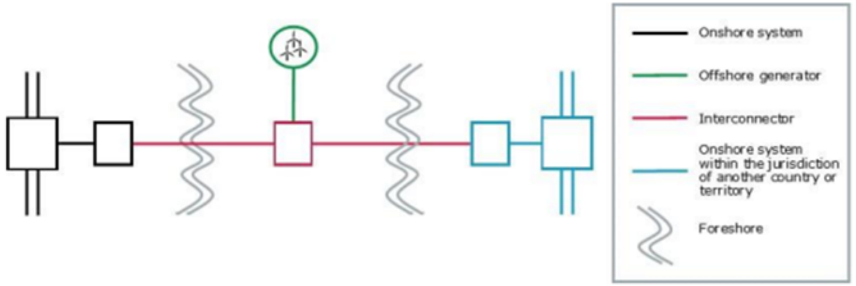
What are the concepts?

Increasing use of HVDC in new ways.

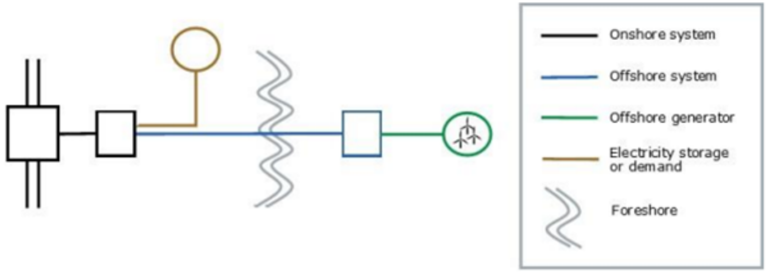
Shared Offshore Transmission



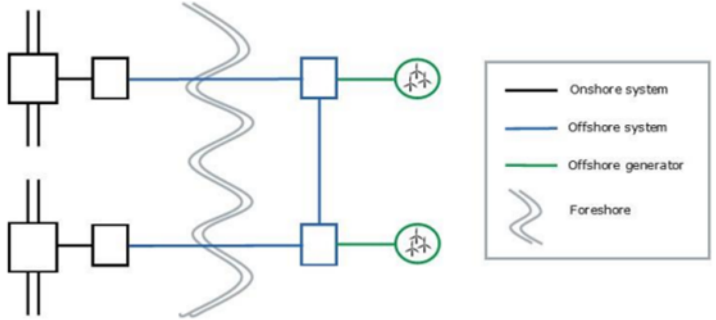
Multi-purpose interconnector



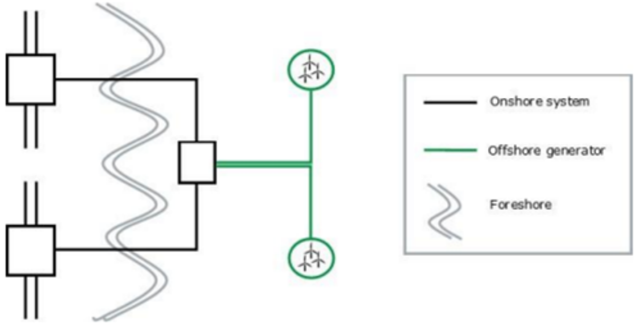
Electricity storage or demand customer Connection to offshore transmission system



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

Scottish & Southern Electricity Networks

TRANSMISSION

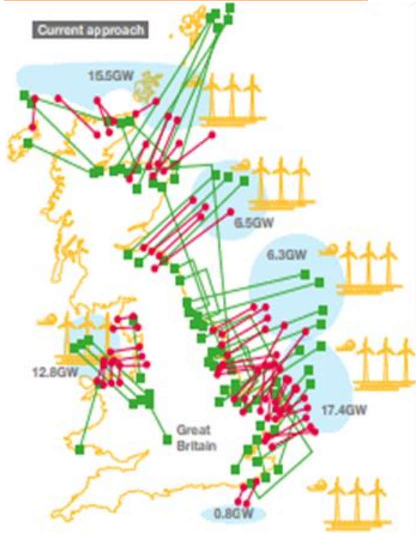
Efficient DC offshore Networks

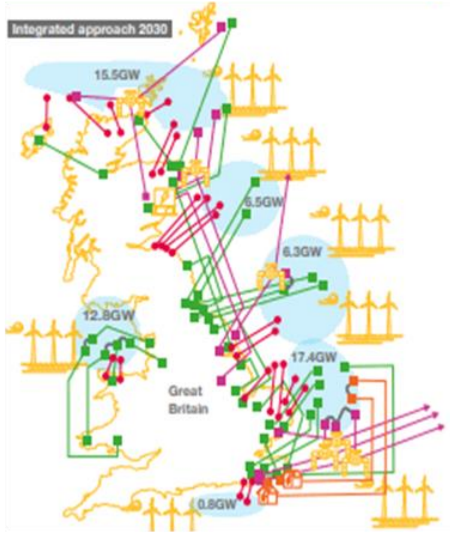
R&D enabling this transition…

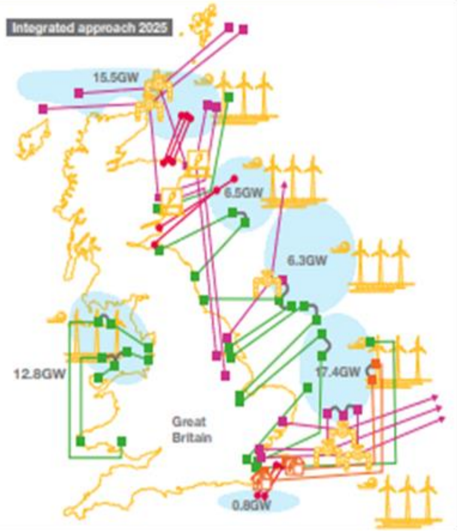
Co-ordinated offshore:

Why is this a new way of doing things?

Status Quo	Integration from 2030	Integration from 2025

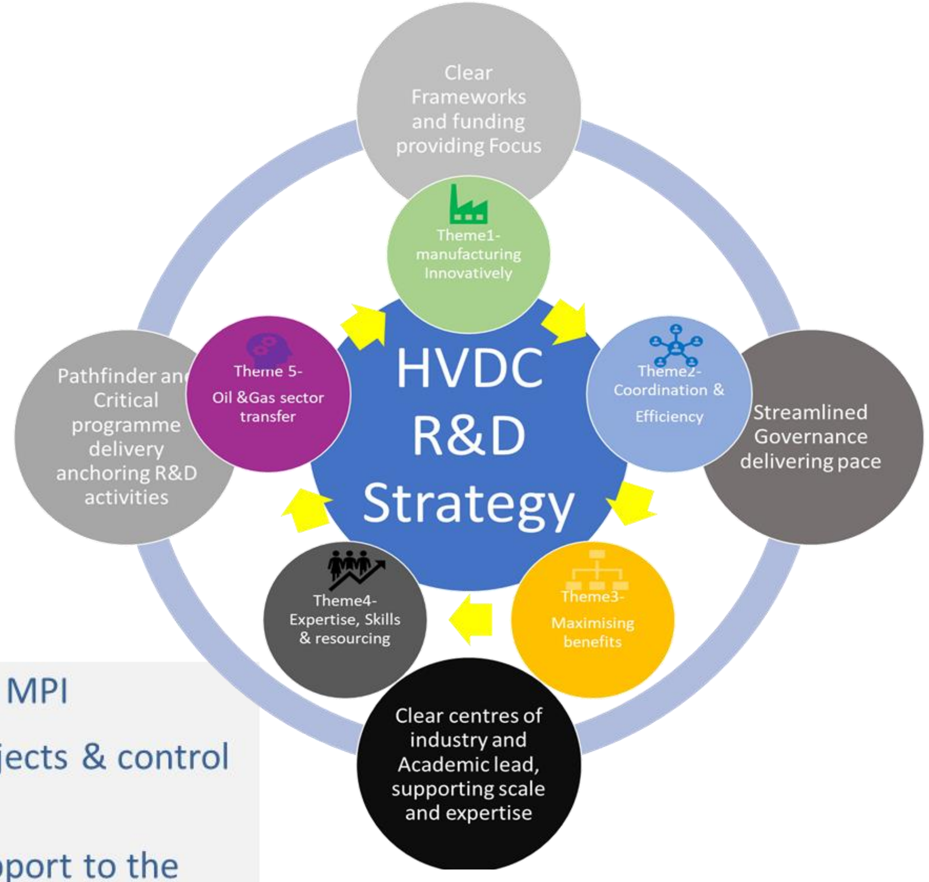






- Point-point Project arrangements
- Onshore performance is project-defined;
- Many individual small convertors, geographically spread on edges of network incrementally harder to deliver; &
- Impacting onshore system reinforcement and driving need for system support.

- 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***

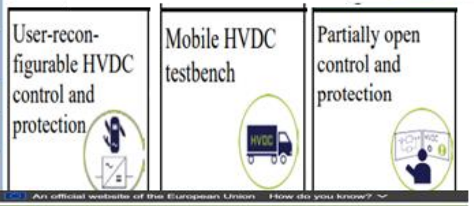


Our R&D strategy for Co-ordinated offshore:

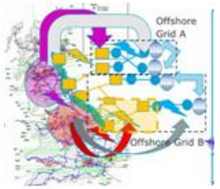
what's does it mean?

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

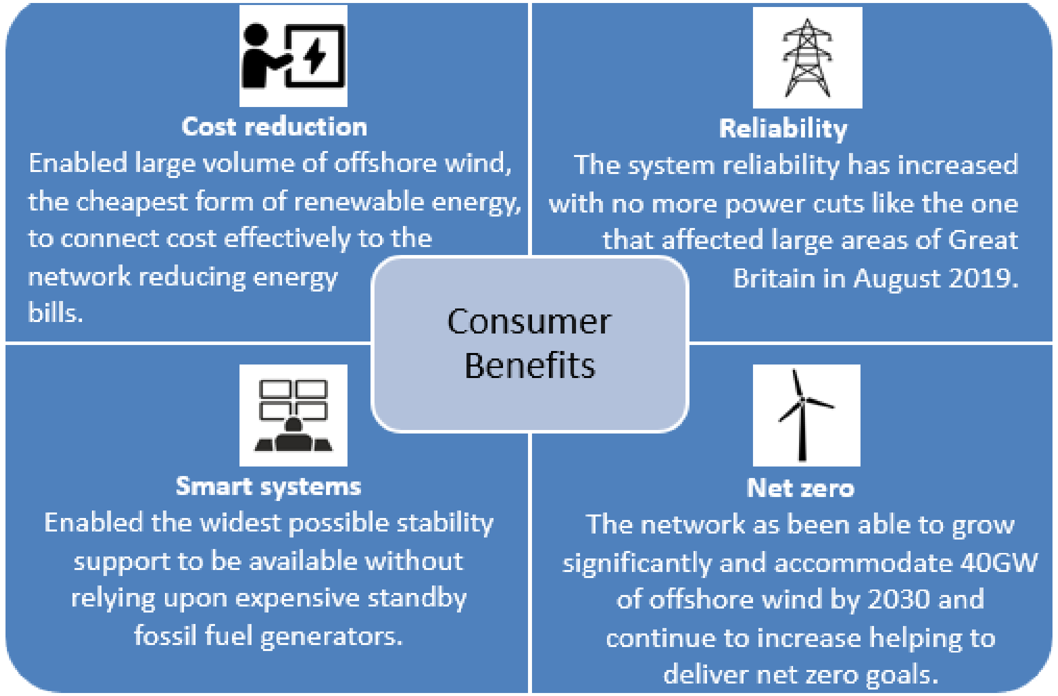
Making it happen.

The arrangements, the initiatives.

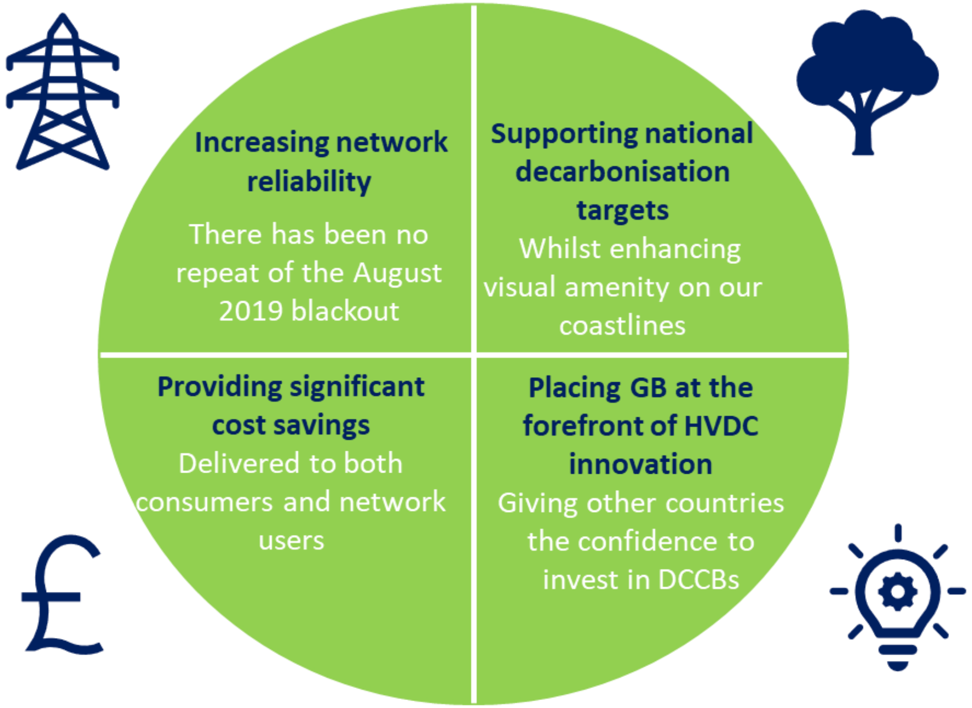
The National HVDC Centre

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)

UKRI Innovate UK

ofgem

Scottish & Southern Electricity Networks TRANSMISSION

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

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.

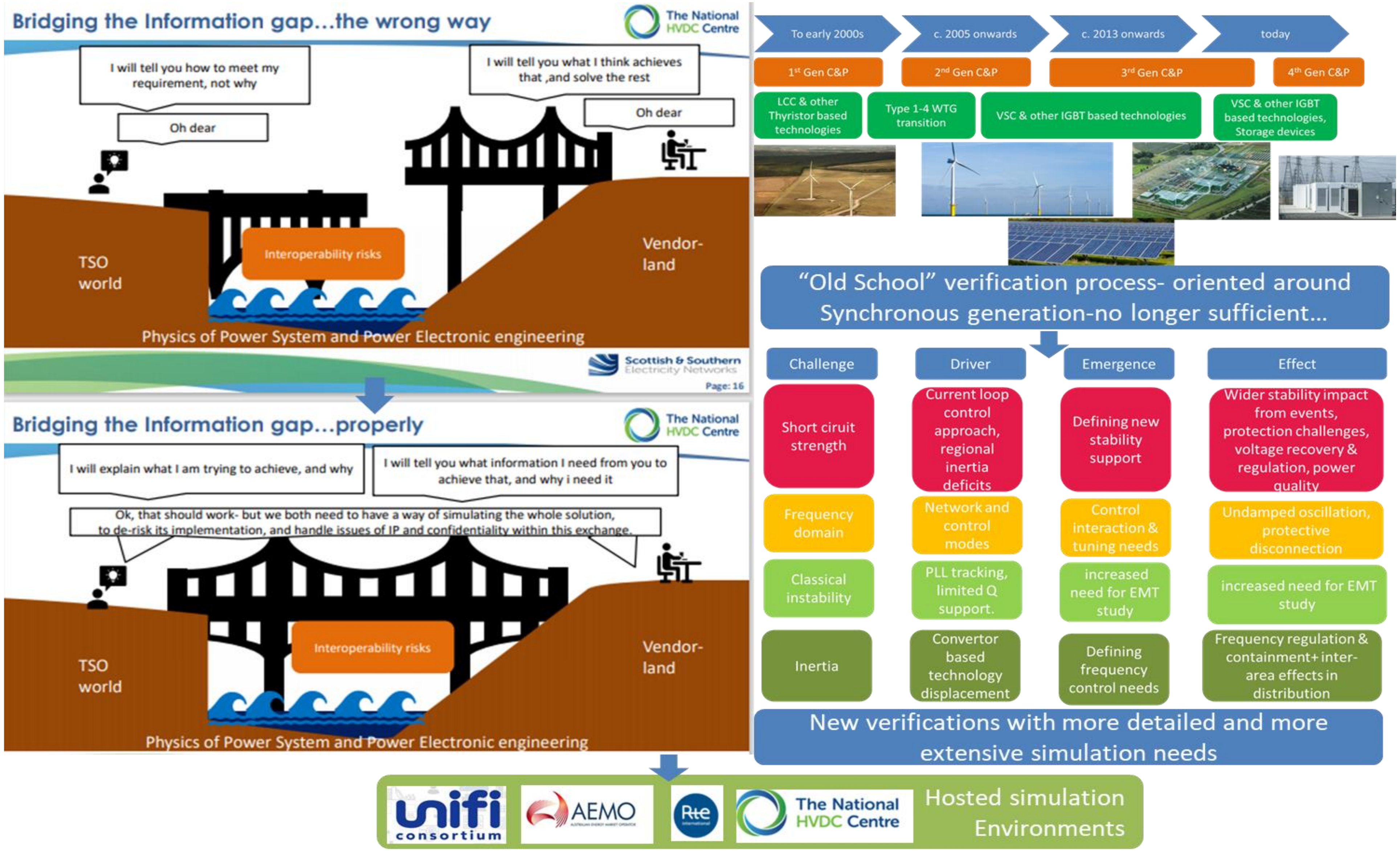
As stated in the offshore renewable energy strategy EN, the rollout of offshore wind and ocean energy, expected to take place in all EU sea basins, requires the development of energy-transportation infrastructure such as HVDC. The technical working group's goal is to support the development and deployment 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.

The National HVDC Centre

Managing a more complex HVDC future

Interoperability is about the dialogue, the tools and the tests; and doing it at Scale..



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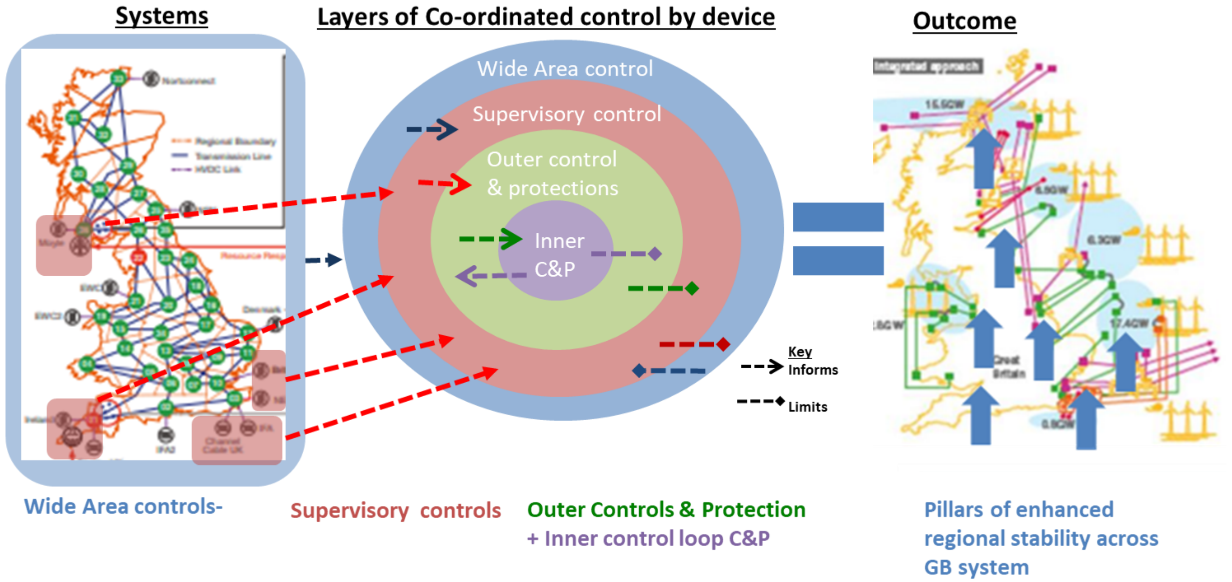
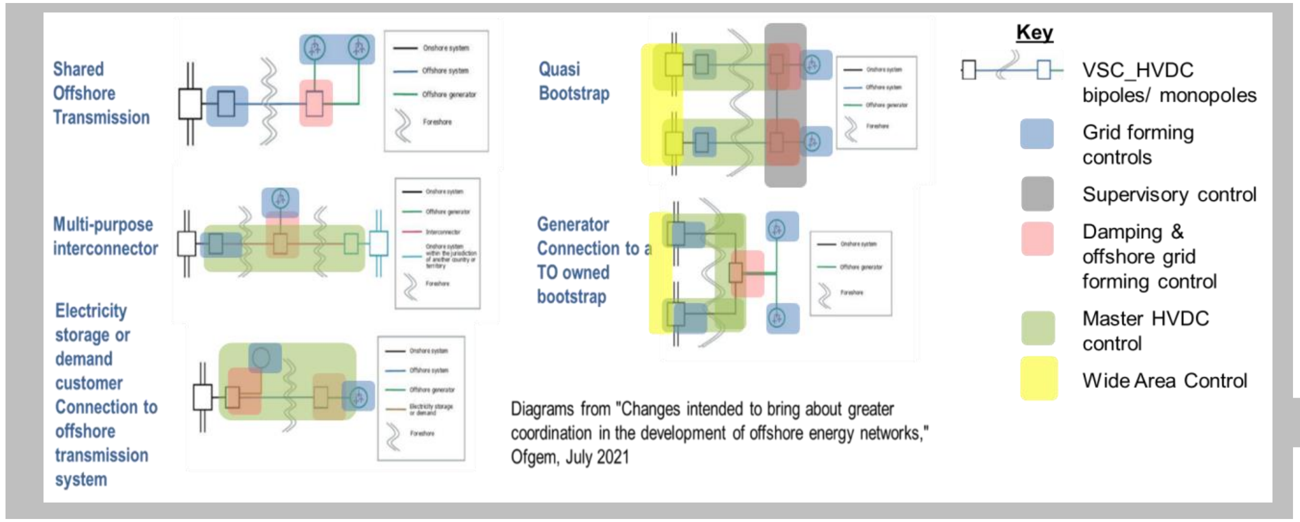
TRANSMISSION

A model for delivering interoperability

Implementing solutions, advising on the transition.

Co-ordinated solutions need to deliver an **array of functions**, **clearly tested**, respecting **interoperability**





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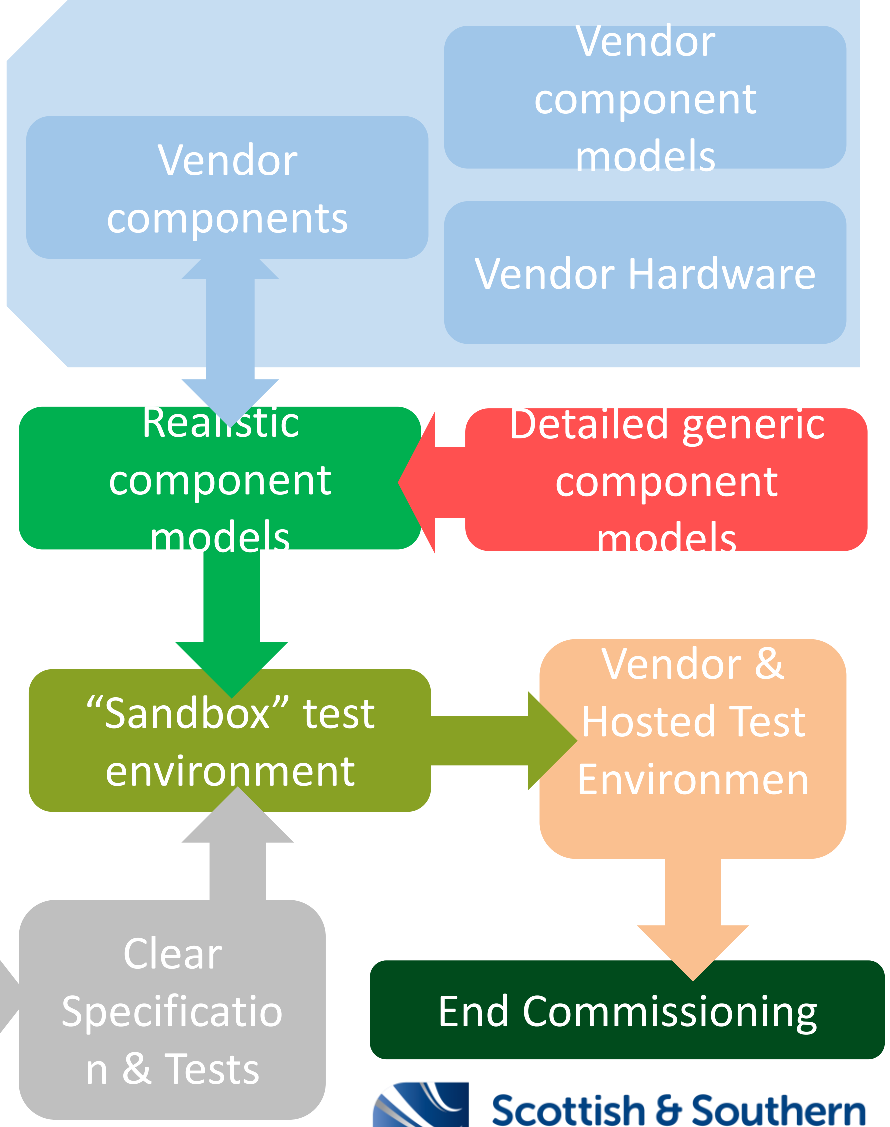
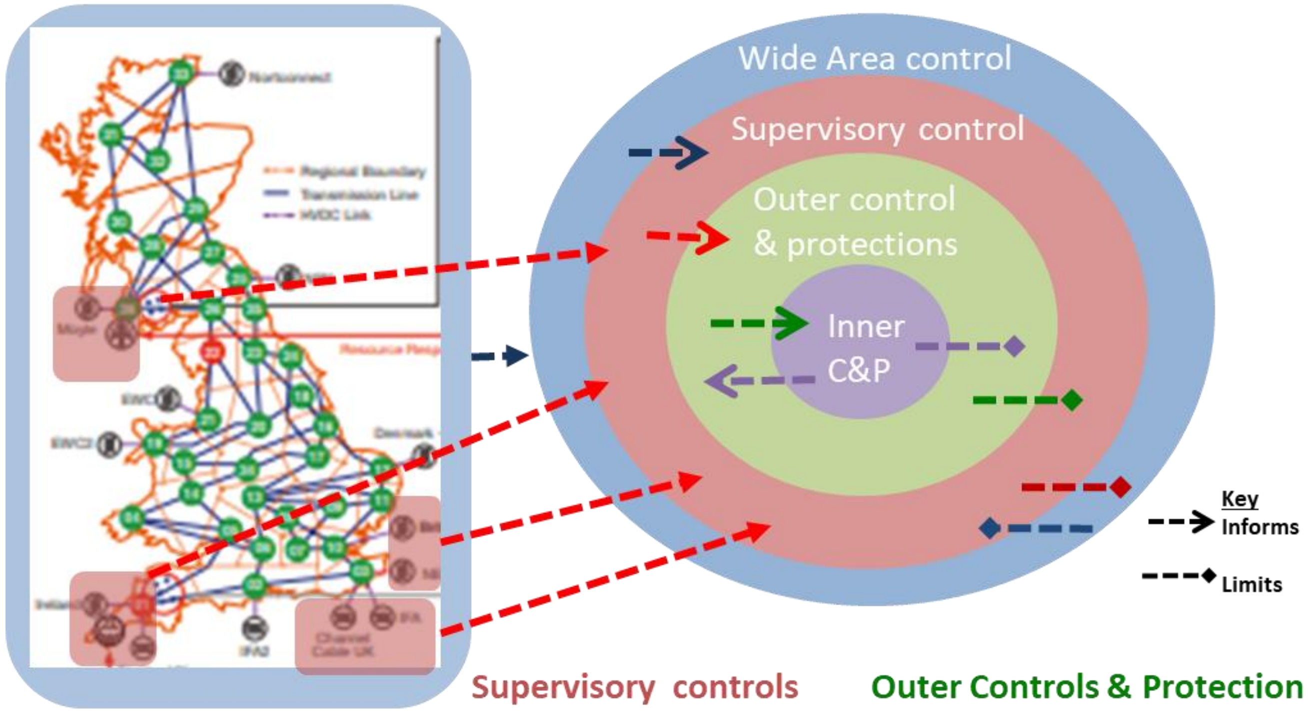


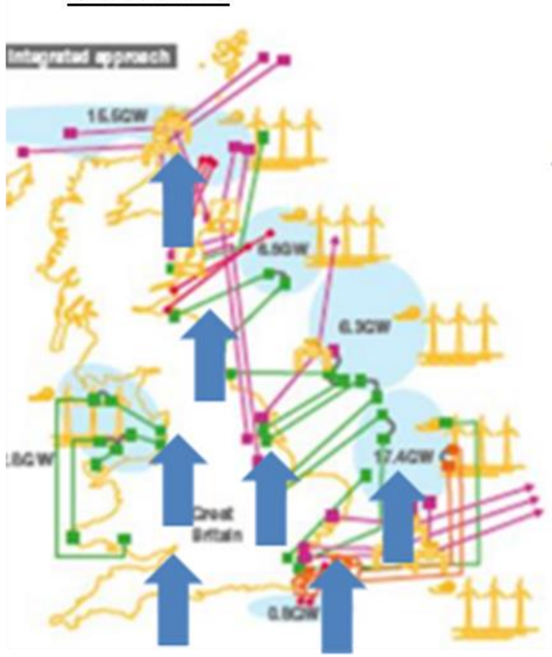
Delivering Interoperability

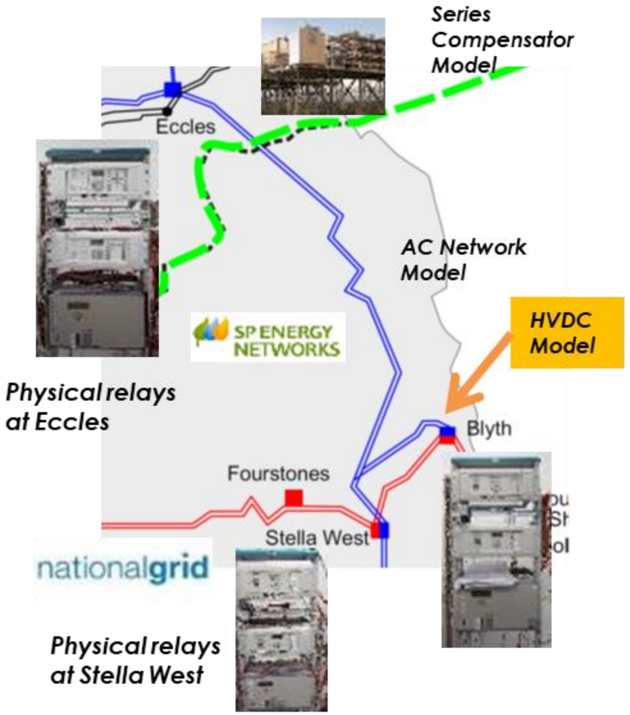
Its not just HVDC itself- but the controls surrounding them. And how you do it.

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.

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The future DC Grids.

The multi-terminal,

multi DC-hub,

multi-vendor DC Supergrids;

and the interoperability at scale that makes that real…

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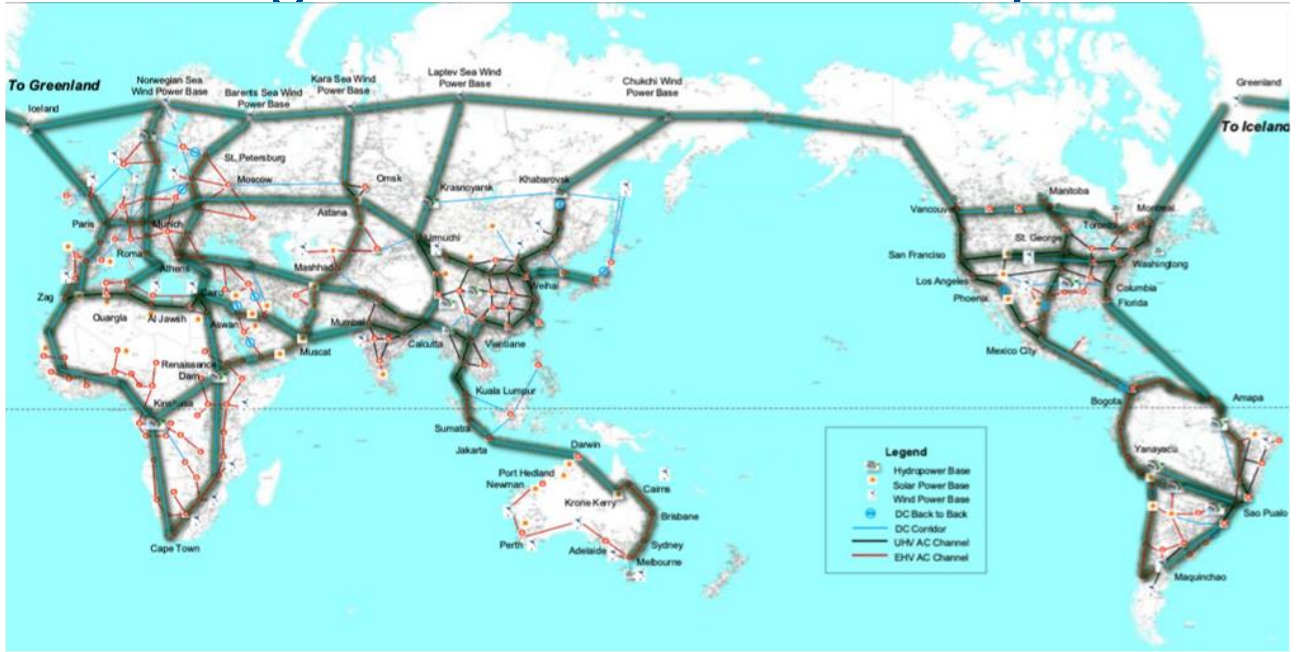
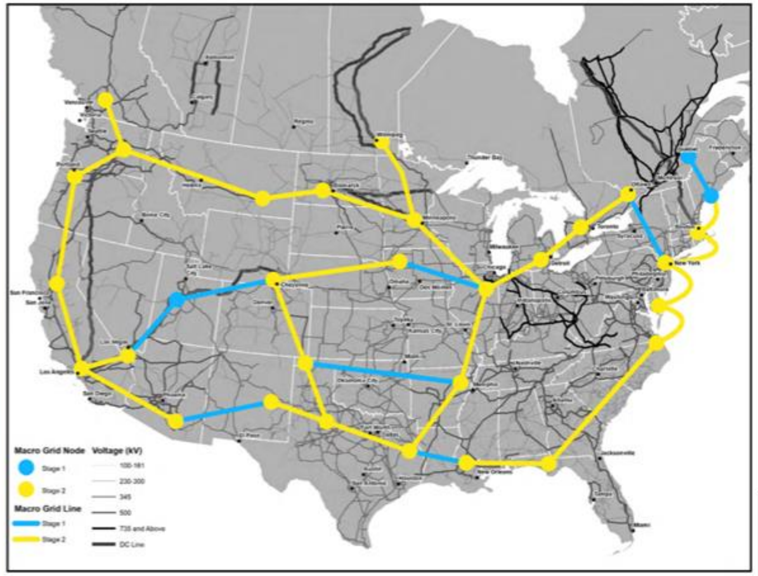
The National HVDC Centre

A Global future of DC grids

Unlocking future network stability and reliability- through achieving interoperability.

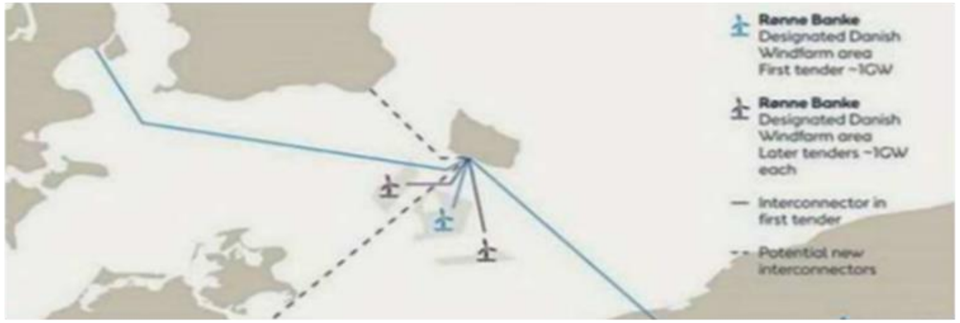


A Global overlay of trans-continental links?



US "Macro Grid" conceptual overlay

North Sea, "DC mesh" concept



Western Baltic "DC Hub"

Eastern Baltic HVDC "spine"

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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…

Thanks for listening.

Any questions, please?

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

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