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Transition toward future DC Grids

Challenges and Possibilities

Ghanshyam Gohil

Hitachi Energy

1 Drivers toward DC Grid

2 Multi Purpose Interconnection

- What is needed
- Where we are

3 Meshed DC Grids

- What is needed
- Where we are

4 Focus on Interoperability for Multi-vendor setup

- What is really the matter

5 Long-term R&D needs

Future scenarios – HVDC overlay and Offshore Transmission

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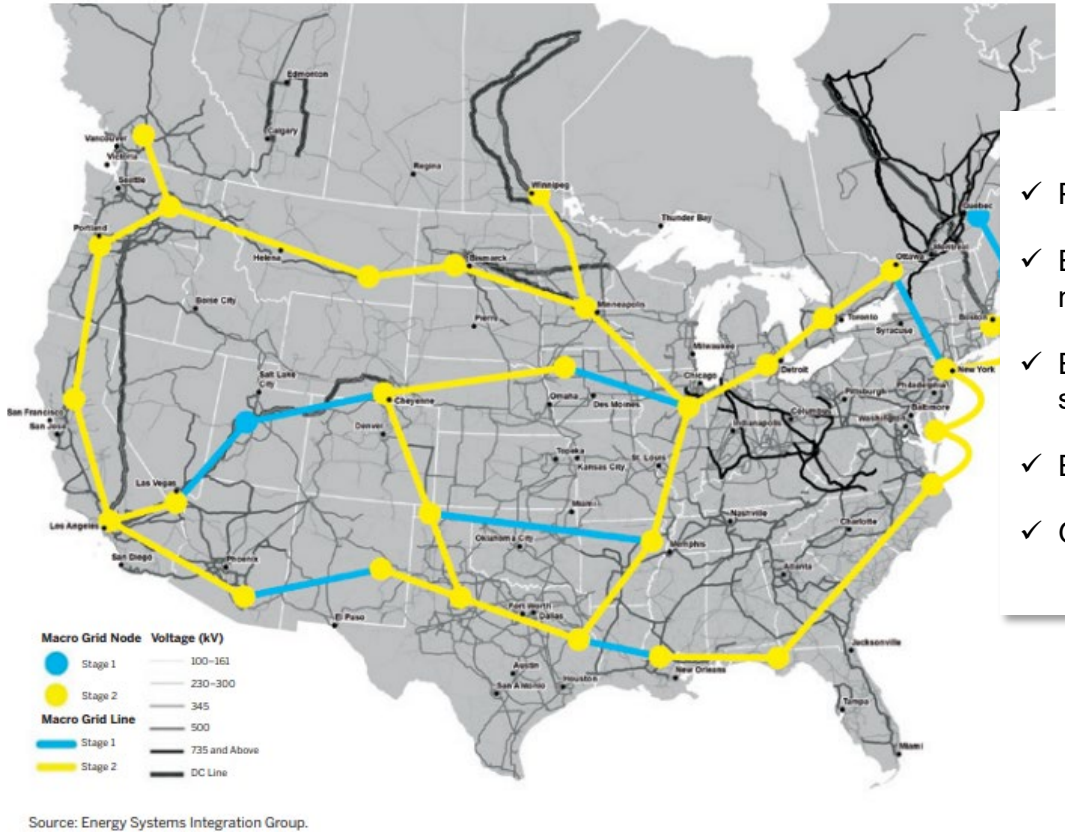
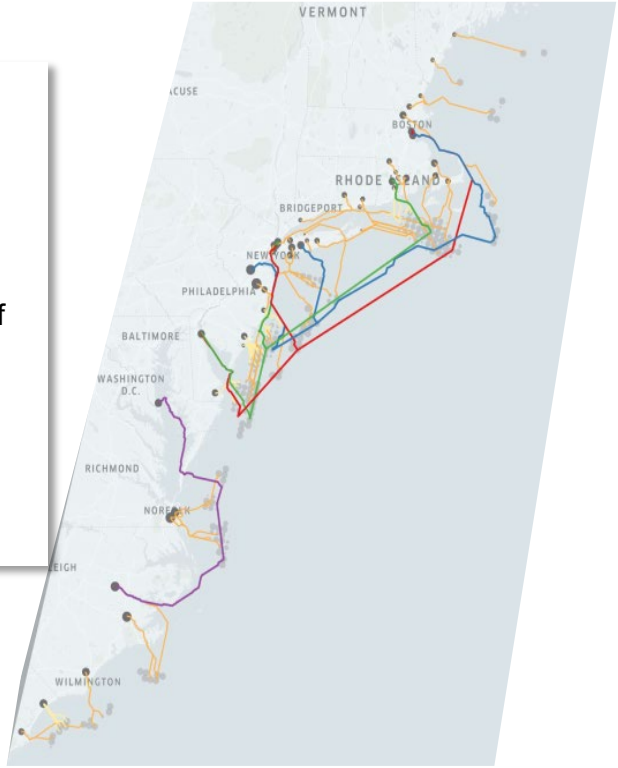
Conceptual Macrogrid Layout from Fall 2020 ESIG Transmission Workshops



Source: Energy Systems Integration Group.

- ✓ Policy and climate goals
- ✓ Economic operation by integrating energy markets
- ✓ Enable efficient integration and diversification of sources
- ✓ Energy security, resiliency, and reliability
- ✓ Grid modernization

Atlantic Offshore Transmission



ESIG-Design-Studies-for-US-Macrogrid-2022.pdf

Atlantic Offshore Wind transmission (BOEM & DOE)

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Future scenarios - Offshore wind expansion

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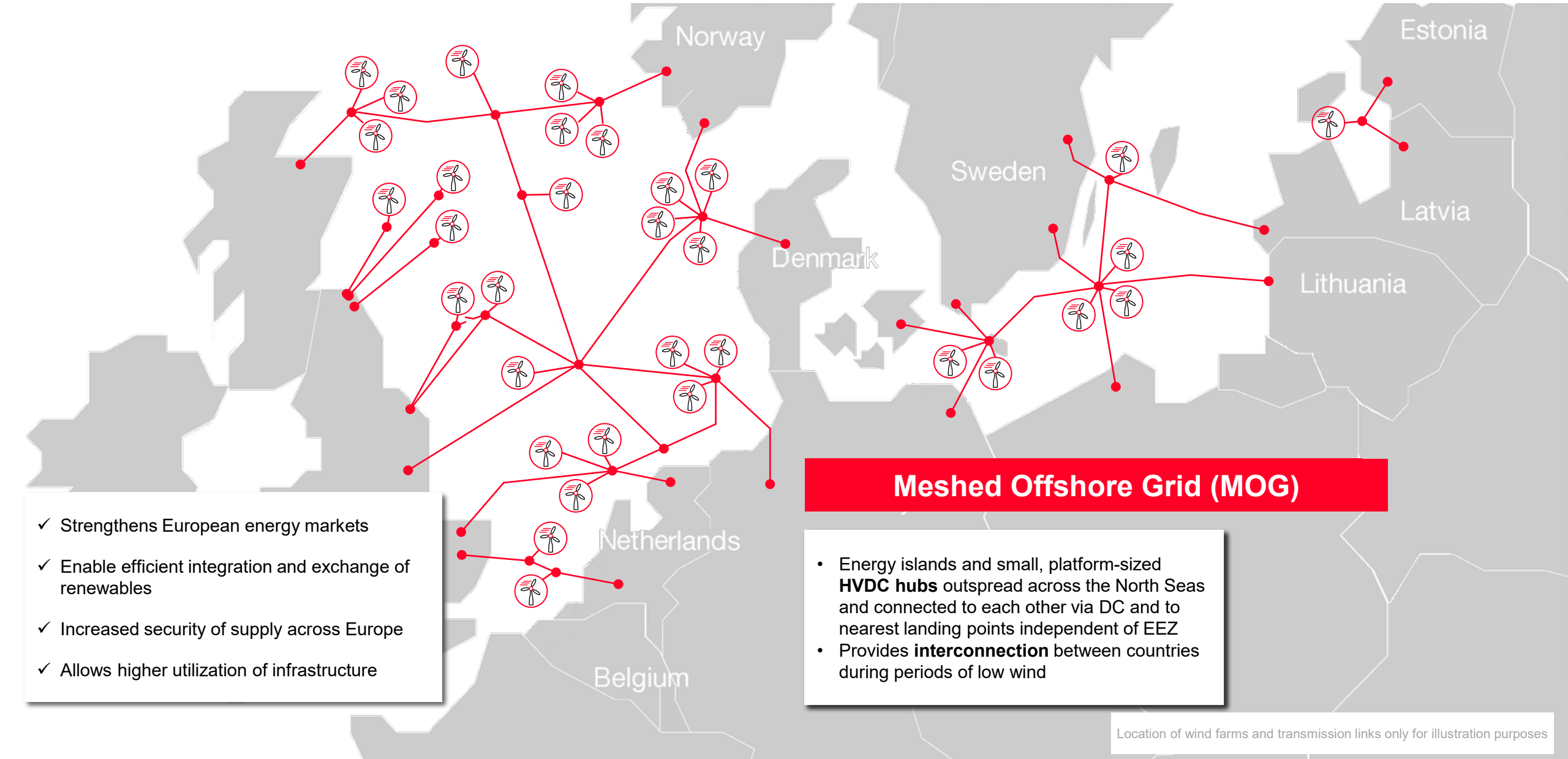

- ✓ Strengthens European energy markets
- ✓ Enable efficient integration and exchange of renewables
- ✓ Increased security of supply across Europe
- ✓ Allows higher utilization of infrastructure

Meshed Offshore Grid (MOG)

- Energy islands and small, platform-sized **HVDC hubs** outspread across the North Seas and connected to each other via DC and to nearest landing points independent of EEZ
- Provides **interconnection** between countries during periods of low wind

Location of wind farms and transmission links only for illustration purposes

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Multi-Purpose Interconnection - MPI

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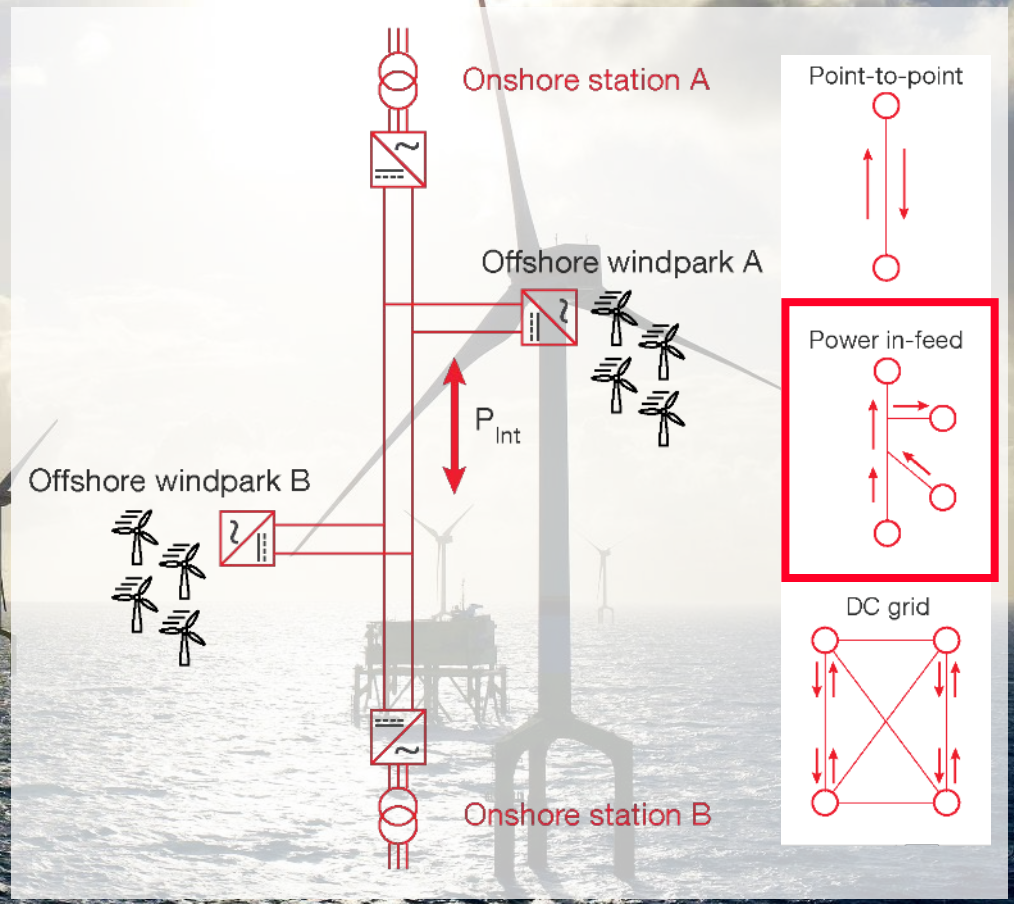
- ✓ Connects two energy markets
- ✓ Integrates (renewable) power sources along the corridor
- ✓ And/or electrifies load along the corridor

Can be built today with existing, proven technology

Typically, a regional DC Grid and defined as a system that constitutes of one protection zone for DC earth faults.

- Normally radial or star network configurations
- Limited power rating
- To temporarily and rarely lose the whole HVDC system has a limited impact on the overall power system.
- Different optimization functions – Control & Protection (Master Control) for multi-terminal operation and grid control



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Multi-Purpose Interconnections

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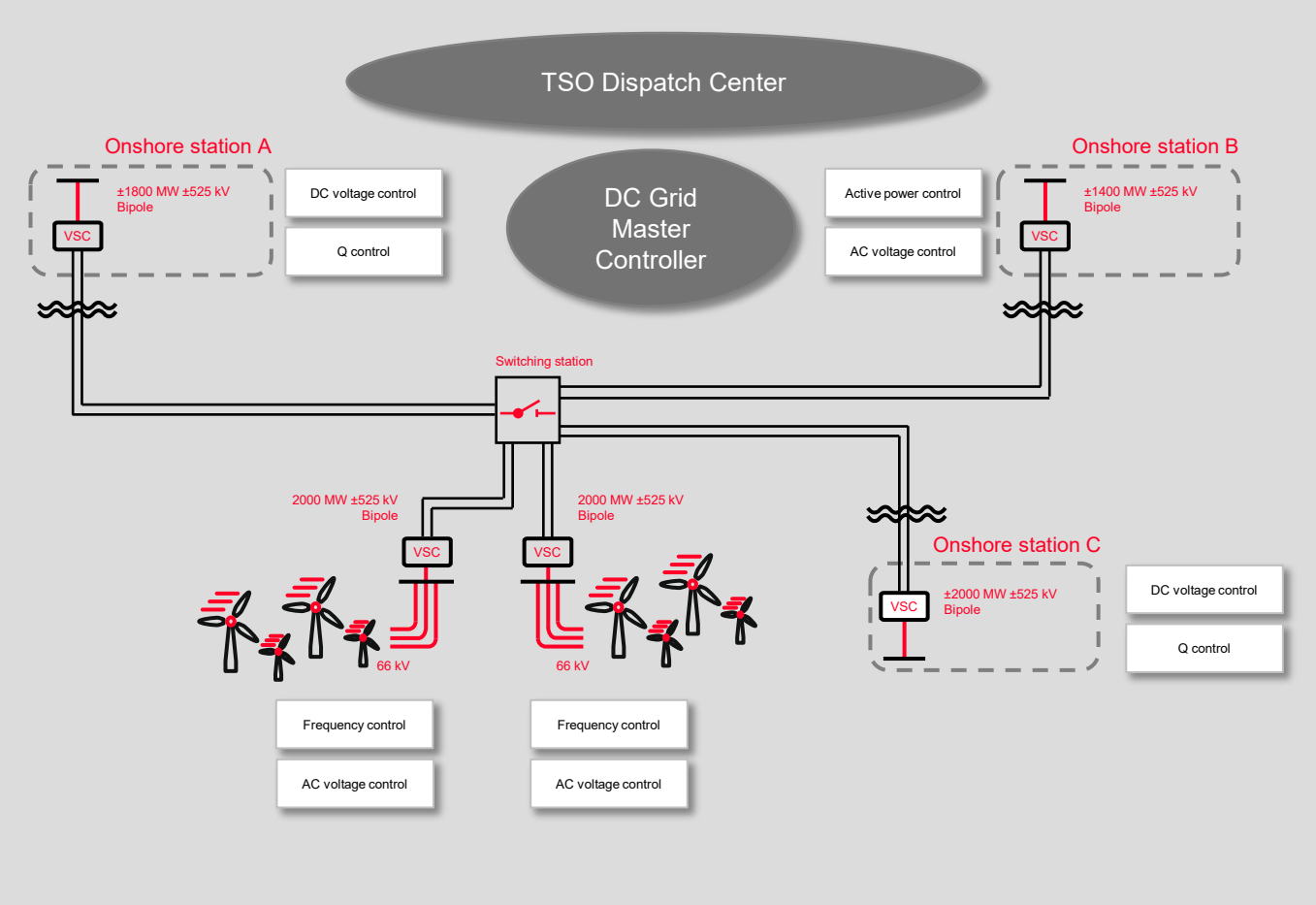

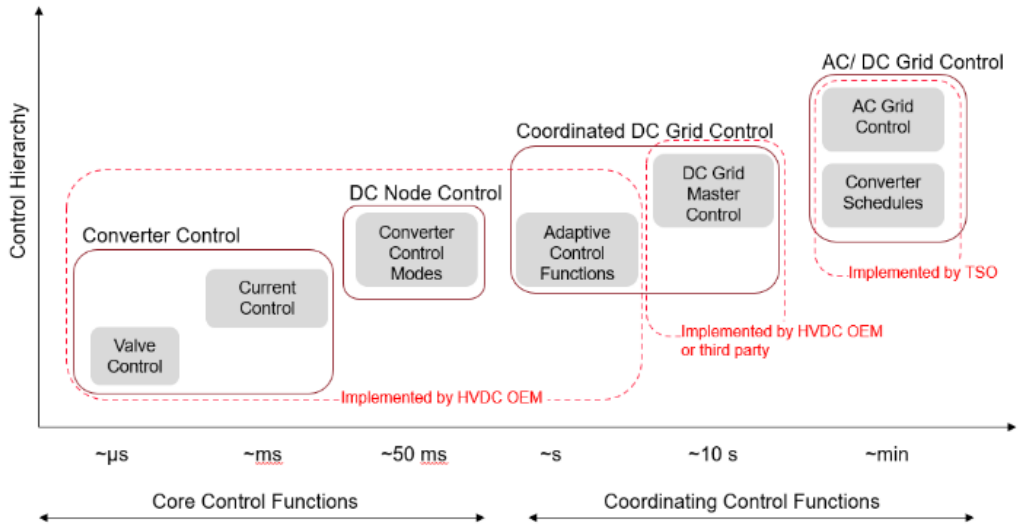

- TSO Dispatch Center (TDC) determines operation
- DC Grid Master Control (DCGMC) communicates with DC Switching Station, all converter stations and with TDC
- DCGMC coordinate power orders, control settings, and sequences for the converter stations and at the DC Switching Station
- DCGMC determines actual configuration, limitations and actual power flows and manages DC switching station re-configurations

MPI – A steppingstone towards a meshed DC Grid ?

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Multi-Purpose Interconnection - MPI

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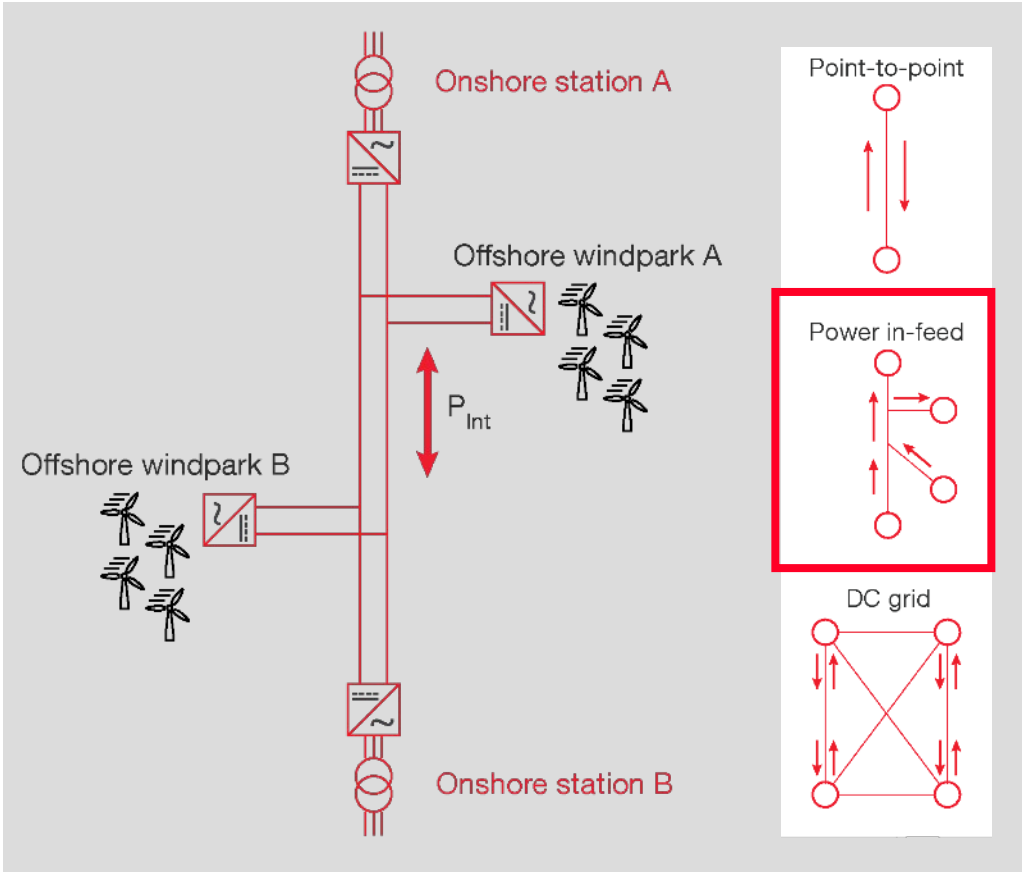
Paving the way

	What is needed?	Hitachi Energy contribution
Technology	MPI Master Controller	Realization of KriegersFlak CGS
	Enable Multiterminal concept	Caithness-Morey-Shetland & other multiterminal links
	DC Switchgear station	
	Define C&P strategies	Share through WG/publications
	DC Protection solution	DC Protection w/ AC Switch
	Interoperability for expansion	
Commercial and regulation	Market regulation or financing	
	New business cases definition	Support RES dev.s, O&G, TSO



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Combined Grid Solutions – Kriegers Flak

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Customer
Energinet.dk SOV, (Denmark) and 50Hertz Transmission Gmb (Germany)

Customer needs
- Interconnecting asynchronous grids
- Connection of offshore wind energy
- Energy trade

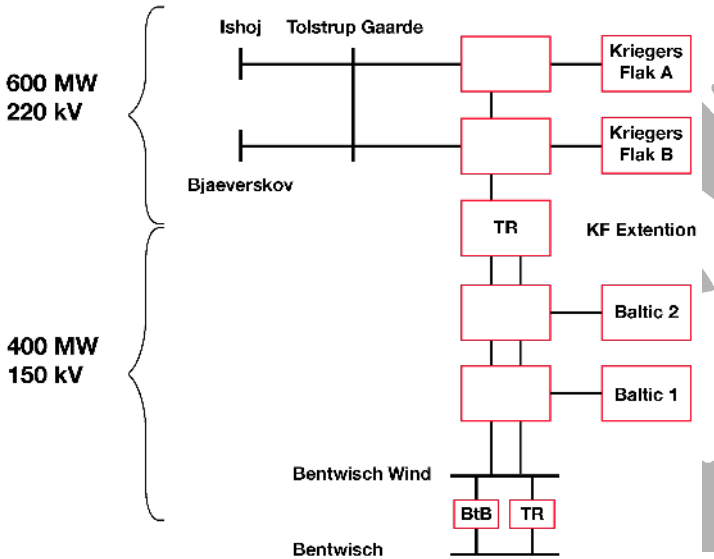
Our response
- 410 MW 140 kV HVDC Light® back-to-back station

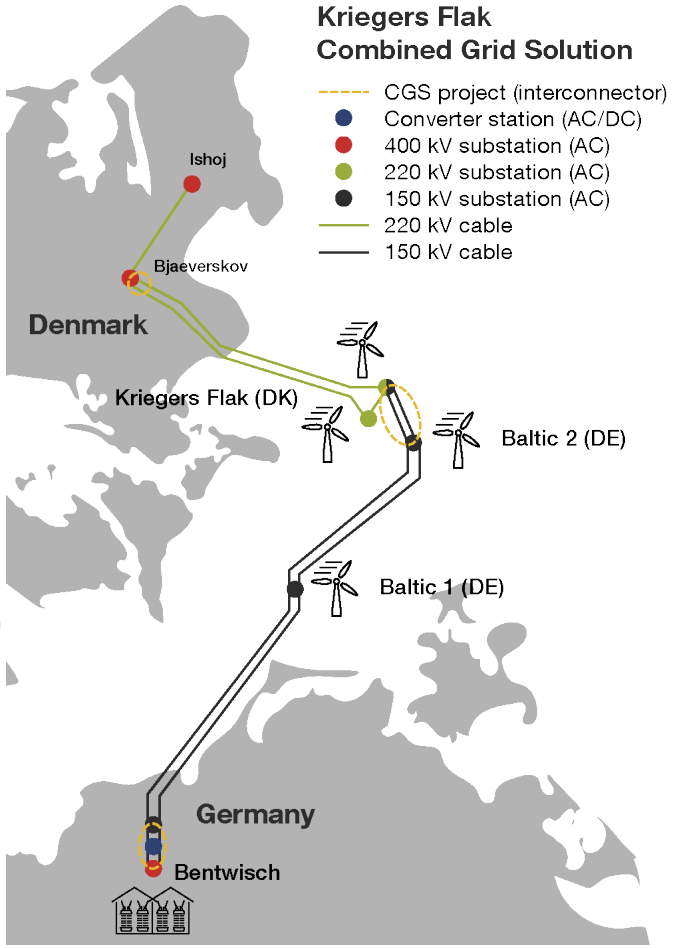
Customer benefits
- Enabling energy trade between Germany and Denmark
- Integrating renewable power from four offshore wind farms into the grid
- Advanced control of the Combined Grid Solution

Year
2019

HVDC Light® converter station

Back-to-back 140 kV station





World's first offshore wind farm connection & interconnector between two countries

NOTE: On demand Hitachi Energy webinar available – **Combined Grid Solutions** – for internal and external use

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The first regional DC Grid in Europe

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Customer
Scottish and Southern Electricity Networks (SSEN) Transmission

Customer needs
To link Shetland to the UK transmission system

Our response
- First multi-terminal HVDC interconnection in Europe, with option of two more terminals
- 600 MW ±320 kV

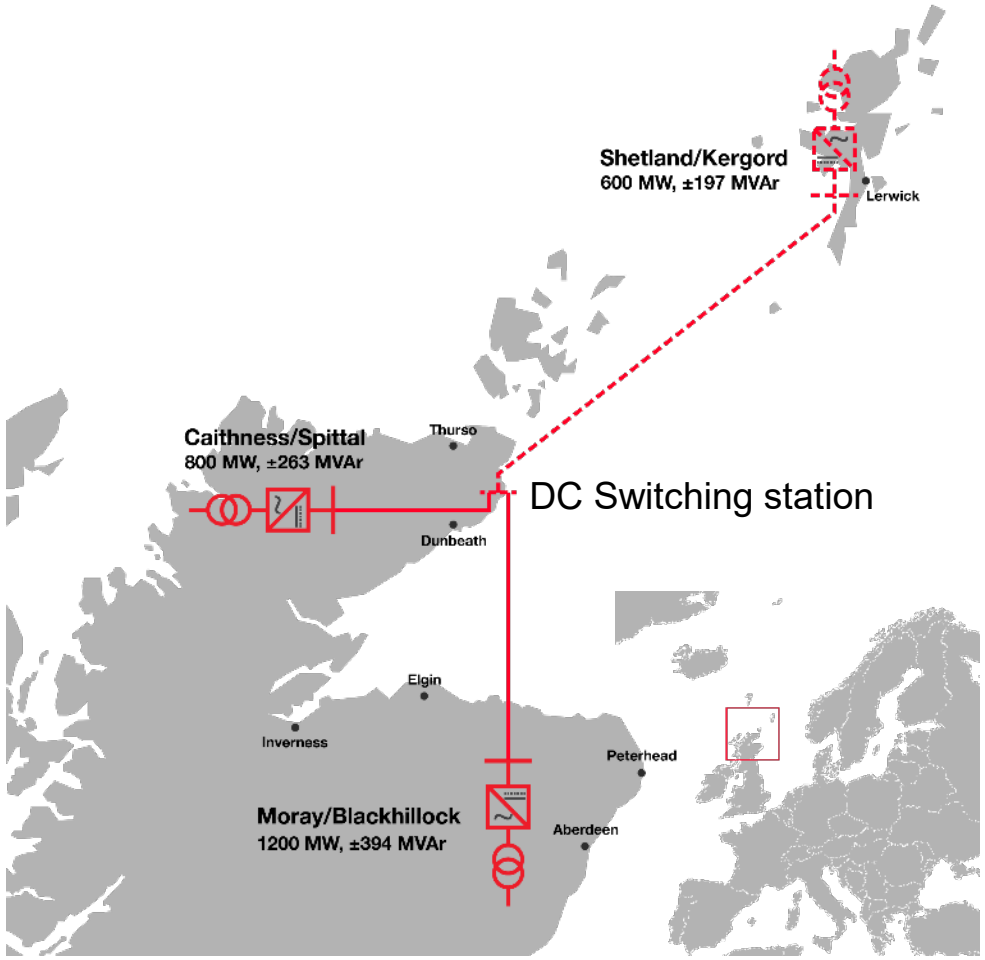
Customer benefits
- Multi-terminal HVDC interconnection provides flexibility to transfer power in multiple directions, based on supply and demand, with minimal power losses
- Boost renewable energy and enhance security of power supply
- Help to connect and transmit wind power generated on the islands to the UK
- Contribute to bringing all greenhouse gas emissions to net zero by 2050

Year
2024

HVDC Light® converter stations

- Symmetric monopole ±320 kVdc
- Blackhillock: 1,200 MW
- Spittal: 800 MW
- Kergord: 600 MW

DC Switching station at multi-terminal connection point



Caithness-Moray-Shetland HVDC Link - Phase 2 – Under construction

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- **Where we are**

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Meshed DC Grids

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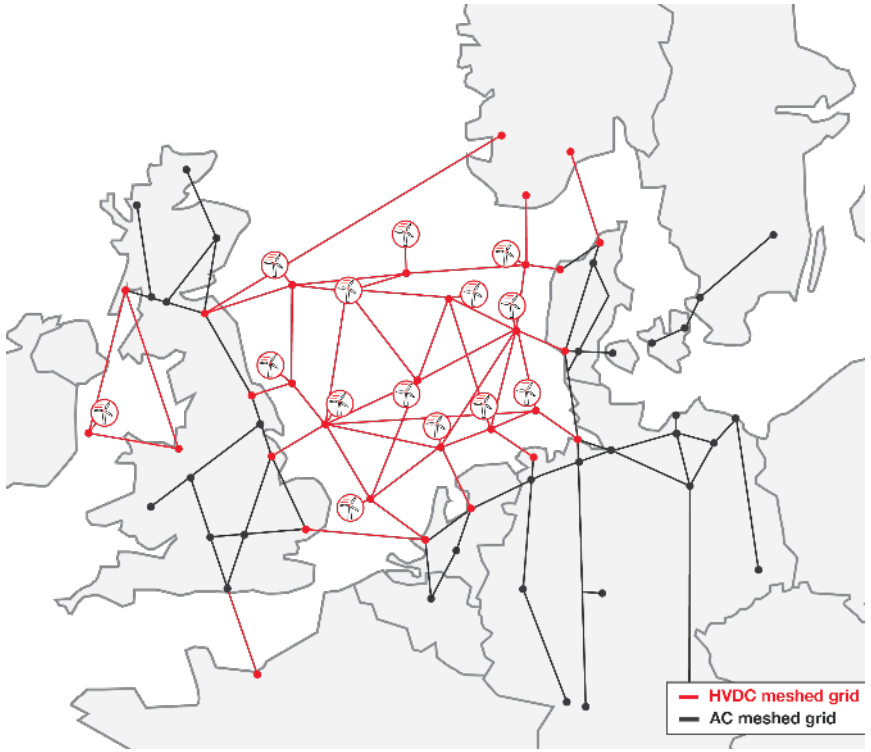
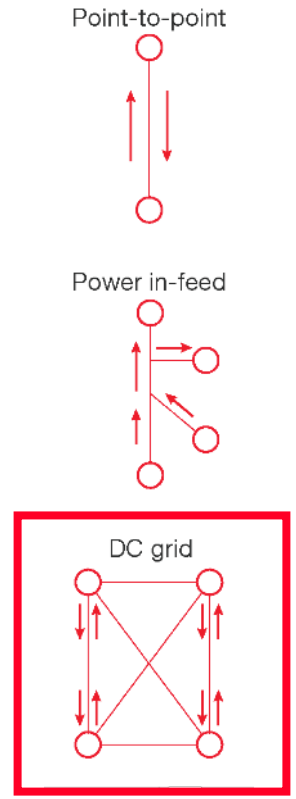
Paving the way

- Strengthens energy markets
- Enable efficient integration and exchange of renewable energy in line with environmental goals
- Increased security of supply across the Region
- Allows higher utilization of infrastructure





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Meshed DC Grids

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Paving the way

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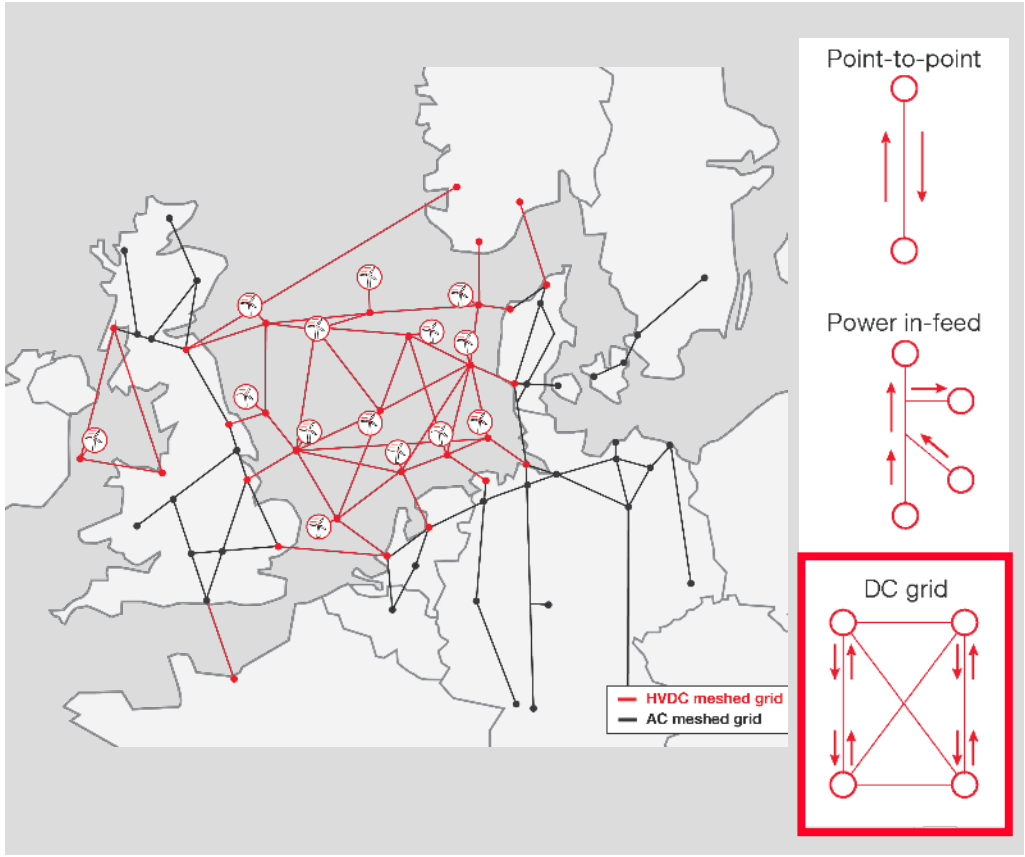
Technology	MPI Master Controller	Realization of KriegersFlak CGS
	Enable Multiterminal concept	Caithness-Morey-Shetland & other multiterminal links
	DC Switchgear station	
	Define C&P strategies	Share through WG/publications
	DC Protection solution	DC Breaker development
Commercial and regulation	**Interoperability for expansion**	
	Technical interoperability	Active in trade associations
	DC GridCode / Ownership	
	New Procurement Process	Support industrial consultations
	New business cases definition	Support RES dev.s, O&G, TSO



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Enabling DC Grid – HVDC Breaker

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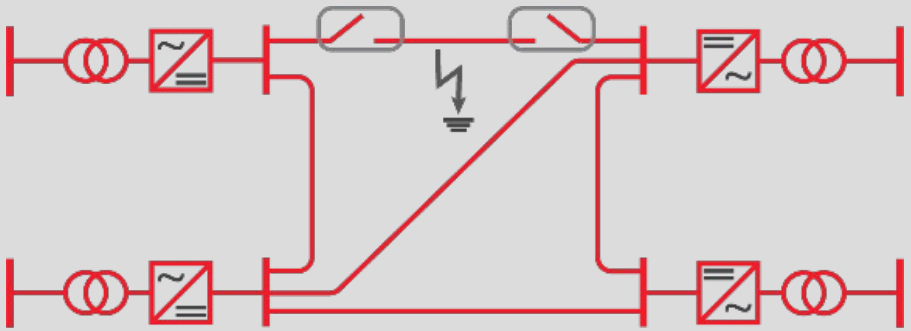
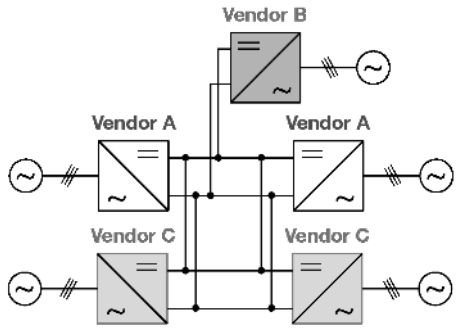
- Enabler for Meshed HVDC grids
- In case of a fault, ensures that only affected part of the grid is disconnected
- Increasing availability and reliability of the system
- Conventional breakers are not suitable for DC grids
- To enable different protection zones in the DC grid

- … through fast response, high reliability, low losses



Half Bridge PEBB + HVDC Breaker combination → Enable fully selective fault clearing strategy and AC voltage support during fault

DC grid technology development



VSC Multi-terminal

Ability to manage different DC lines from 1 station

- TRL[1] level 8, Hitachi Energy demonstrated the technology
- Multi-terminal ready and multi-terminal prepared
- Project examples: NordBalt and Shetland

DC breaker

Ability to isolate fault current on DC mesh

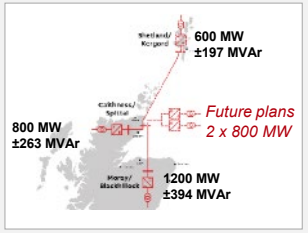
- TRL[1] level 7, Hitachi Energy demonstrated the technology
- Demonstration in 2020: 350 kV, 20 kA power range
- Demonstration as part of EU-funded PROMOTioN project

DC meshed grid C&P

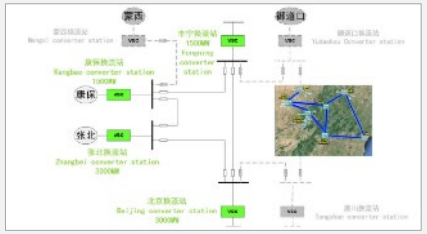
Ability to supervise power flows across a DC meshed grid

- TRL[1] level 6, Hitachi Energy active at CIGRE WG
- Technology development of control and protections algorithm done
- Simulation part of DC grid program

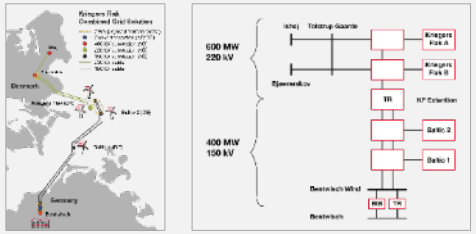
Caithness-Moray Shetlands grid



Zhangbei DC grid project



Kriegers Flak CGS



1. Technical Readiness Levels – scale from 1 to 9 where 9 corresponds to “Actual system proven in operational environment“

Meshed DC Grids

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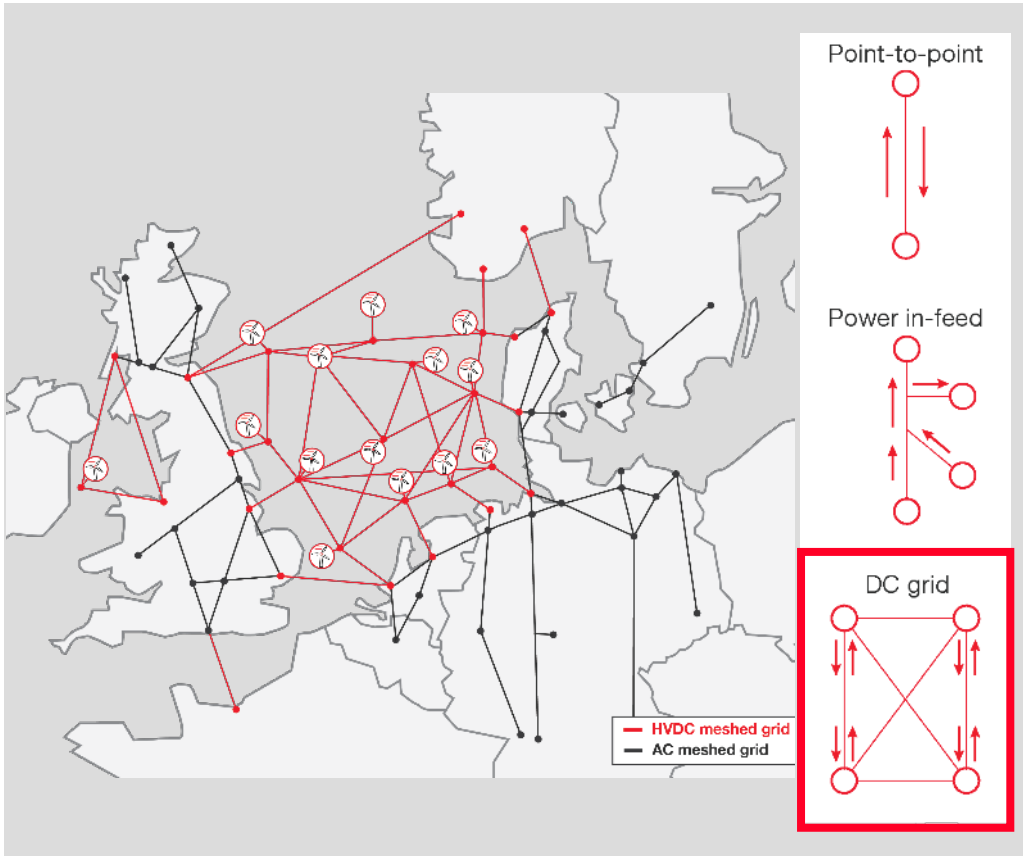

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HVDC Interoperability – DC grid evolution

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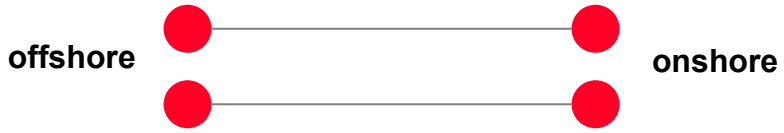
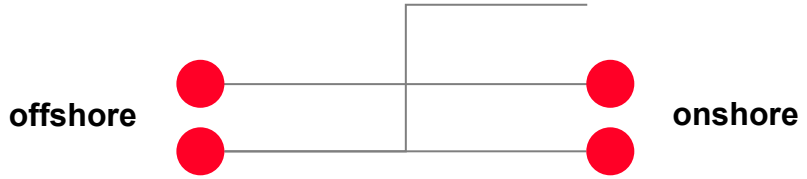
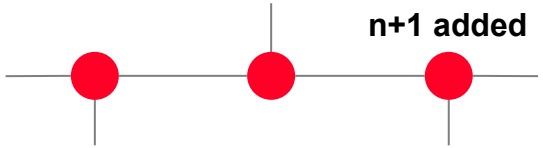
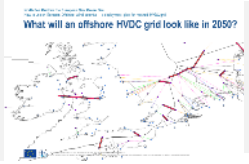
Current situation

Point-to-Point (P2P) connection	
Standalone “black-box” dual converters	
Single vendor	
System design after EPC award	Tender → EPC Inc. systems design → Operation
Examples	 **Dogger Bank** P2P Developer connection  **Dolwin5** P2P TSO connection

Upcoming situation – Multivendor setup

Meshed grid connection	
Collection of “open-box” single converters	
Multi-vendors	
System design before EPC award	FEED Inc. system and DC grid control update → EPC → Operation
Examples	 **Ijmuiden Ver** Possible NL-UK single line multi-terminal  **North Sea offshore** meshed DC grid

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HVDC Interoperability – Functional Grid Code solution

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Existing "Point-to-Point" HVDC system

HVDC Station

HVDC supplier

IEC/ANSI specifications

AC grid side

HVDC Station

(90 years of R&D)

DC line side

System Operator

AC Grid Codes (HVDC version)
Ex: Network Code HVDC

SCADA/EMS

HVDC supplier

No Grid Codes

Future HVDC grid system

HVDC Station

HVDC supplier

IEC/ANSI specifications

CLC/TS 50654-1 „HVDC Grid Systems and connected Converter Stations"

AC grid side

HVDC Station

(90 years of R&D)

DC grid side

System Operator

AC Grid Codes (HVDC version)
Ex: Network Code HVDC

SCADA/EMS

Key elements to be set

DC system coordinator

DC Grid Functional Specification (driven by TSO)

HVDC controller (driven by OEM)

Ensuring interoperability with AC grid codes and DC functional specifications

Responsibility | Applicable documents | Grid system controller

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Hitachi Energy Involvement

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Under NDA!

Hitachi Energy has been, is and will be main active player in defining DC Grids of the future

Project driven by SuperGrid Institute and collecting consortium of (HVDC system manufacturers, TSOs, third party HVDC system integrators, wind turbine manufacturers, offshore wind farm devel.

Main objective:

Enable interoperability of multi-vendor HVDC.

Main Hitachi Energy task:

Control and Protection Development and System Integration in Multi Vendor Environment

With nearly 40 leading organizations from research, industry, utilities, and transmission systems operators. Hitachi Energy part of the project, together with Siemens, GE, Toshiba. 50Hertz, Elia, Terna, EnerginetDK, Statnett, RTE, Red Electrica examples of Utility partners.

Main Objective:

Project will help to overcome the challenges of integrating renewable energies into Europe's energy mix.

Technical Committee with participation from Hitachi energy, Siemens, GE and different European TSOs.

Main Objective:

Development of guidelines for HVDC Grids Systems.

Task completed, approved EU standard "HVDC Grid Systems and connected Converter Stations – Guideline and parameter List for Functional Specification"

Base for InterOPERA work.

Ongoing translation to an IEC standard.

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DC/DC Converter

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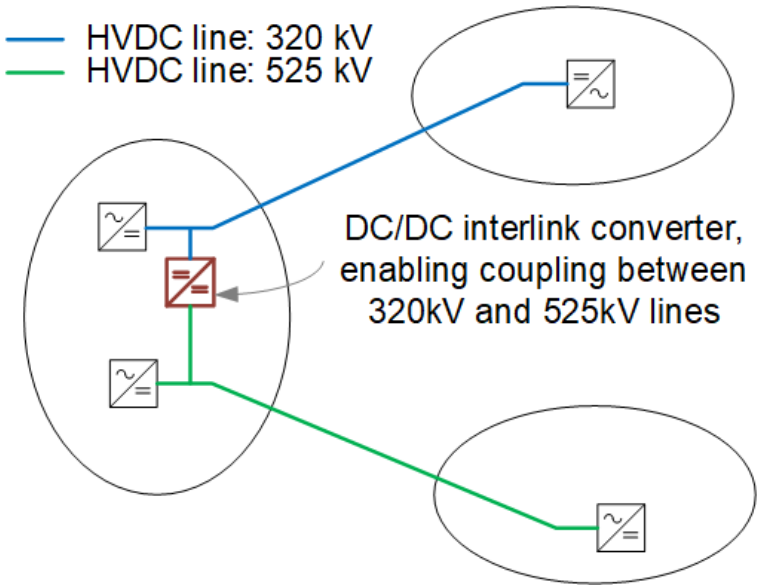
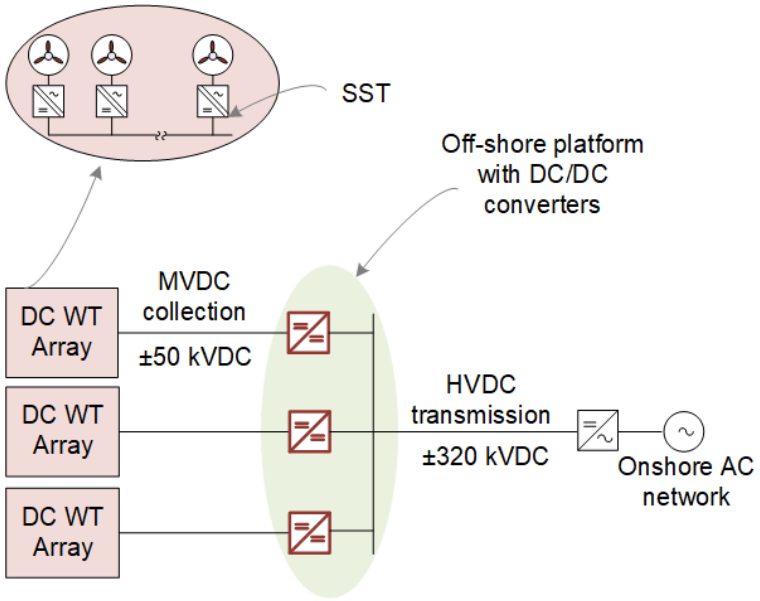
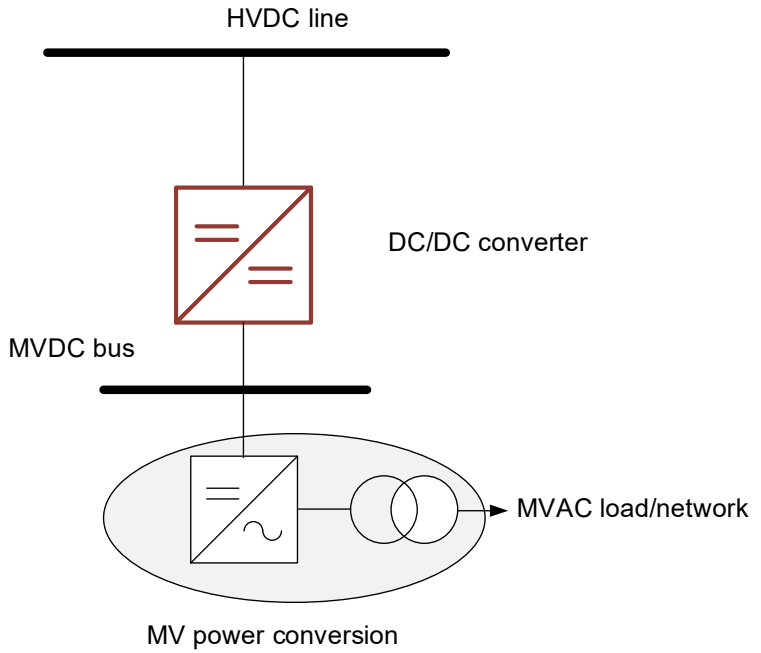
Inter-linking of existing HVDC lines



DC WT with MVDC collection



HVDC Tapping



- **Optimal and cost-effective DC/DC converter?**
- **Fault-handling in DC/DC converter?**
- **Further investigation into the technical feasibility of DC/DC converter is required.**

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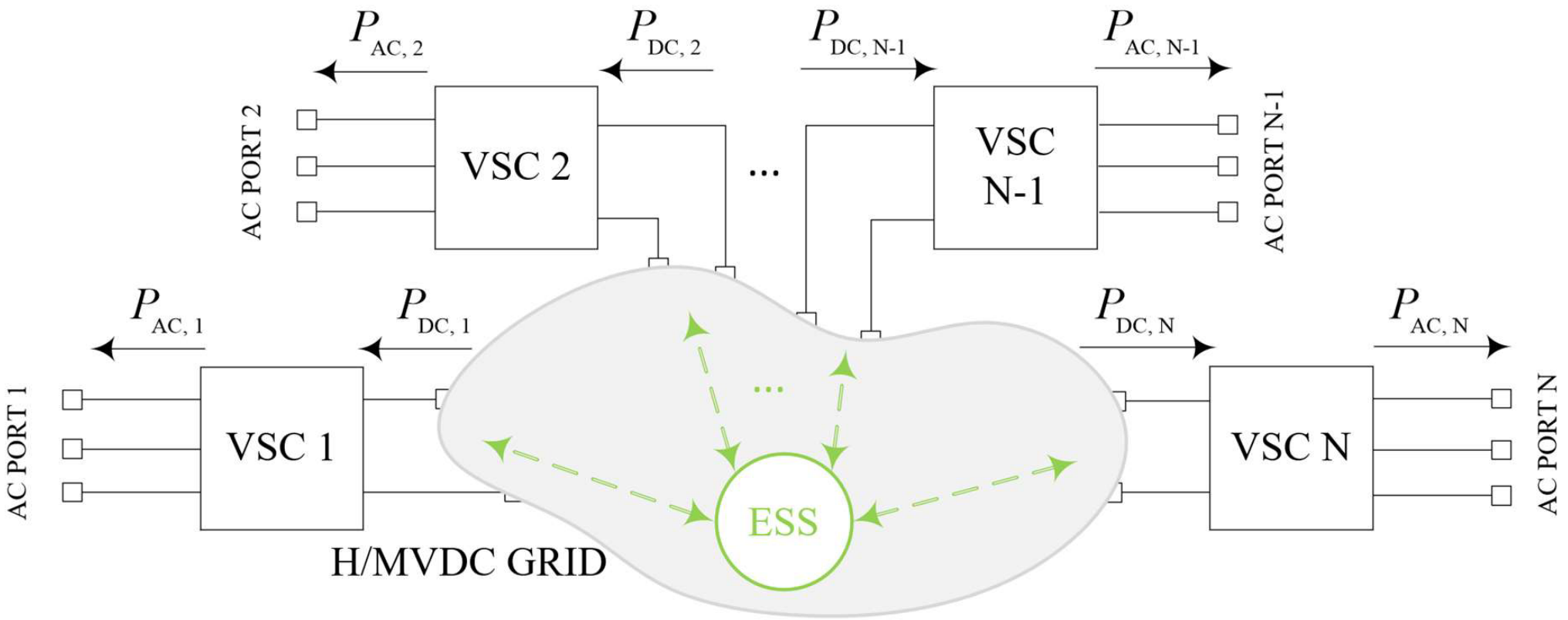
Energy Storage



- **AC-coupled vs DC-coupled storage?**
- **Centralized vs Decentralized?**

Power Flow Controllers

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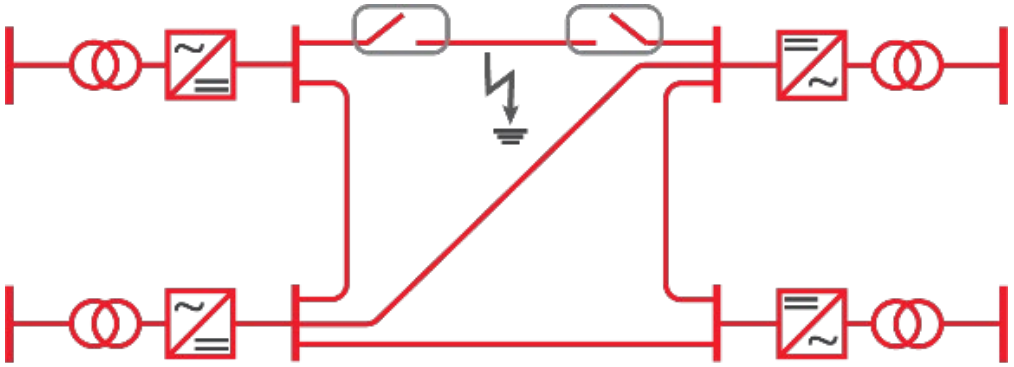
Meshed DC grids



Power Flow Controller

- Is there any need for converter-based power flow controller (PFC)?
- How many PFCs are required?
- What is the most optimal way of realizing PFC?
- Role of PFCs in avoiding voltage instabilities, black-start

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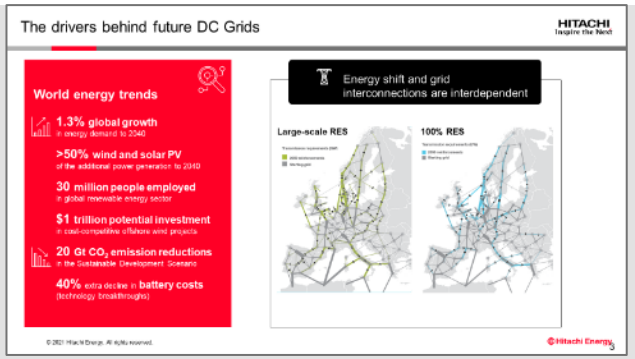
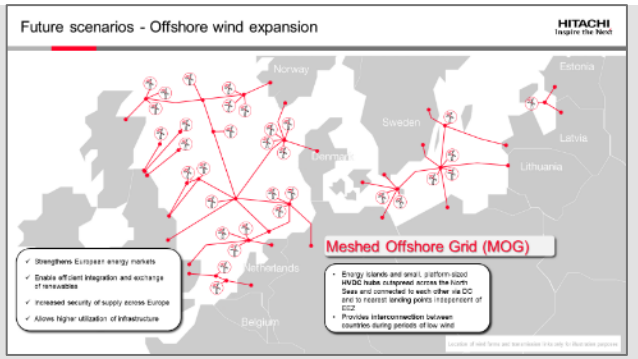
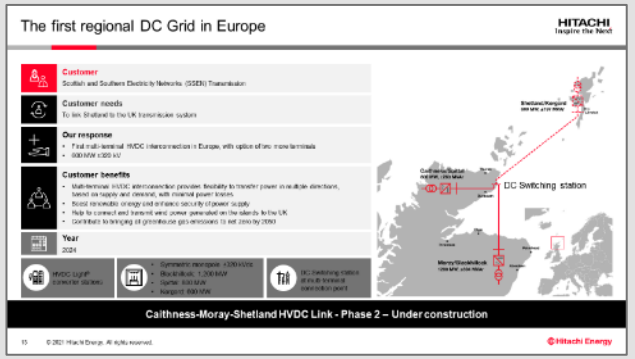
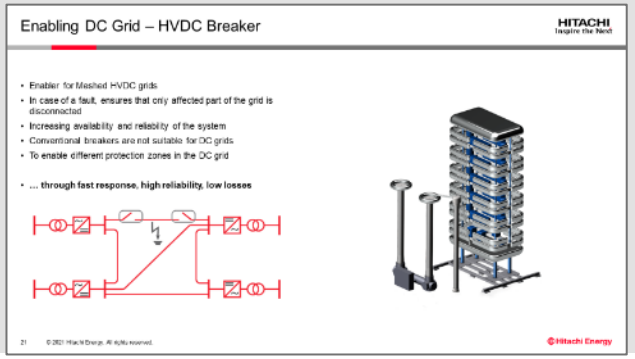
Conclusive remarks

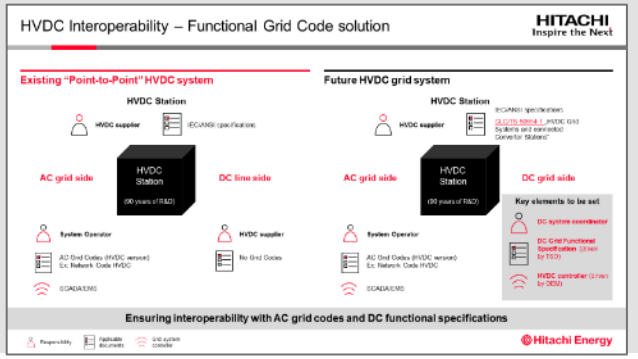
- DC Grid is **enabler to energy transition**
- **The DC Grid will evolve**
  (Point-to-Point – Energy HUB – MPI – Meshed)
- Hitachi Energy has been, is, will be **key active player in industrial initiatives**
- **All concepts are in place, risk is manageable**
- We support DC Grid scalability through **Multi-Vendor Interoperability**
- **Interoperability is not only OEM technical matter!**
  (Regulations, DC Grid Code, Functional Spec, planning activities, business models, procurement…)









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Multi-Purpose Interconnections

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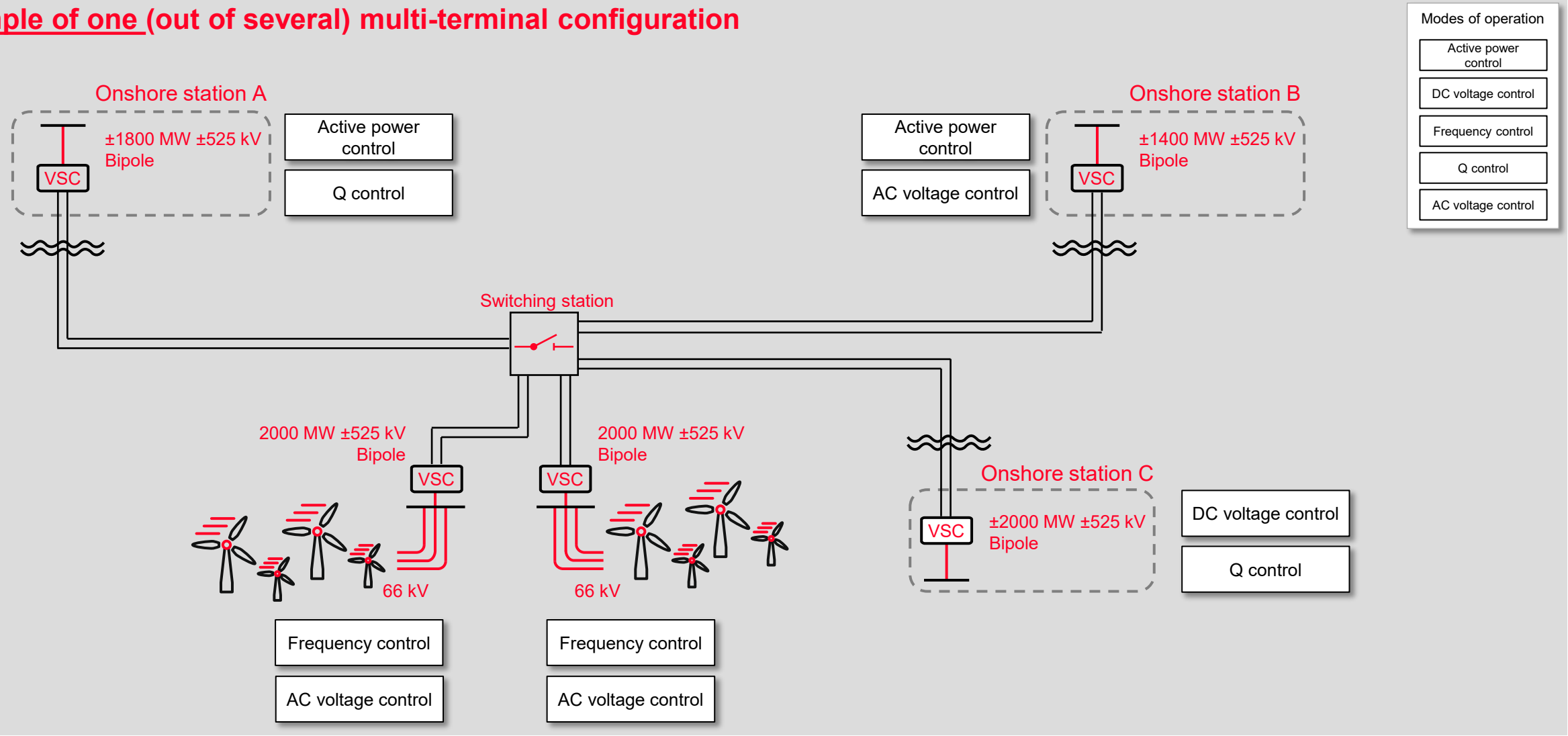
Example of one (out of several) multi-terminal configuration



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Multivendor experience

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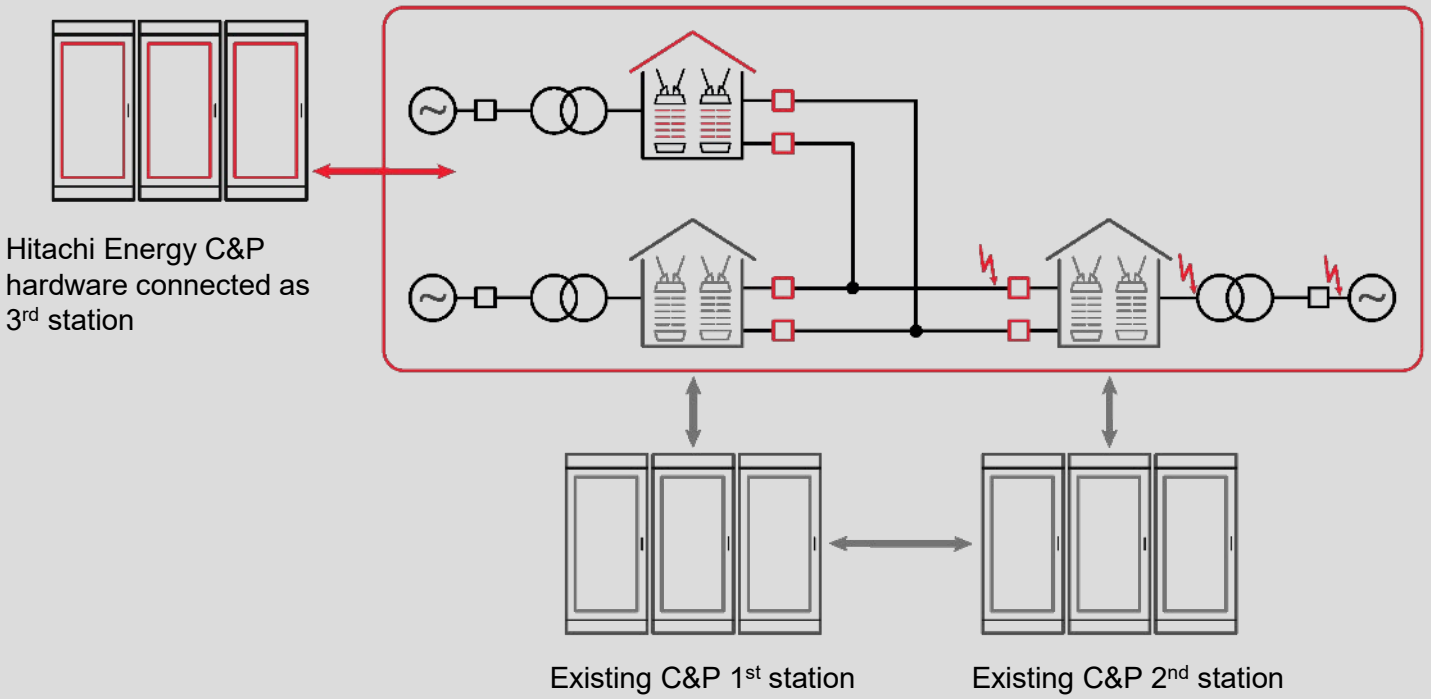
Best Paths
PROJECT

- Hitachi Energy the only remaining vendor for the real-time studies with C&P hardware.
- However, realistic multivendor studies were performed.
- Hitachi Energy connected as 3rd station to an existing point-to-point link delivered by another vendor.
- Hitachi Energy connected as well as 2nd station in a point-to-point setup.
- Since Hitachi Energy was the only active vendor, all tuning and all changes were made in Hitachi Energy ’s C&P setup. The already existing C&P equipment from the other vendor was not tuned or changed.



Hitachi Energy

Multivendor experience - Successful interoperability tests

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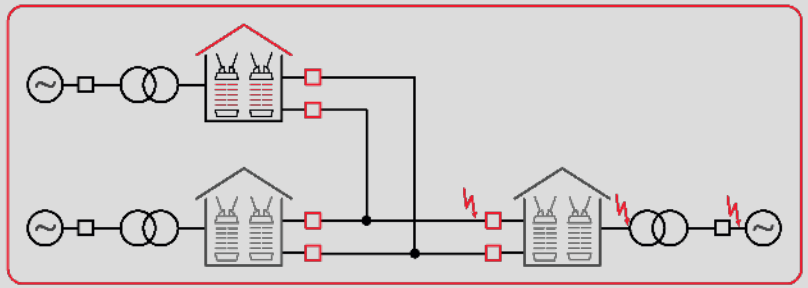
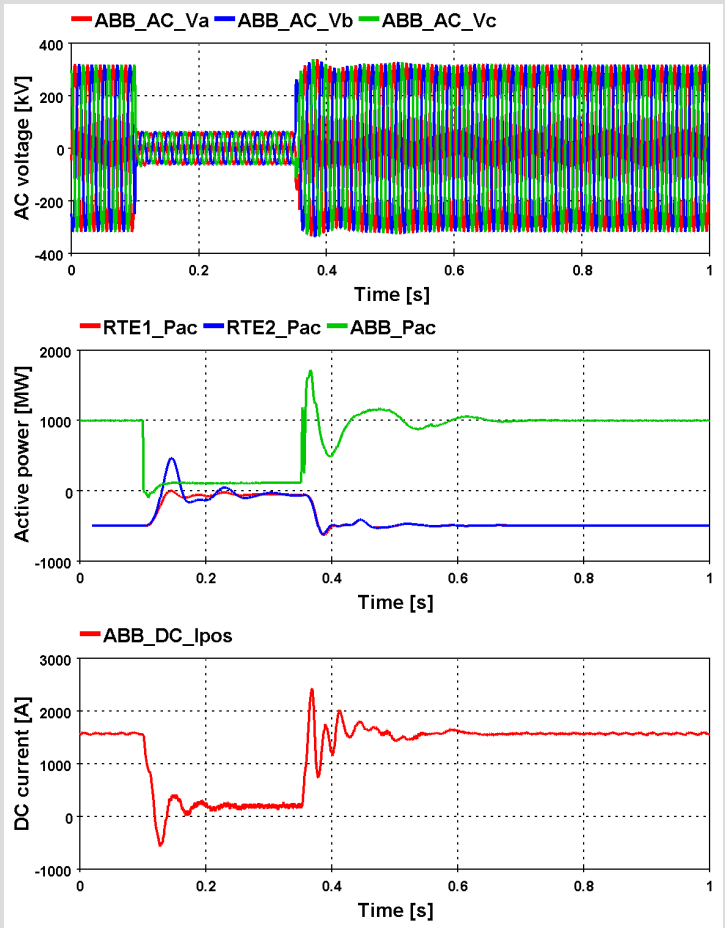
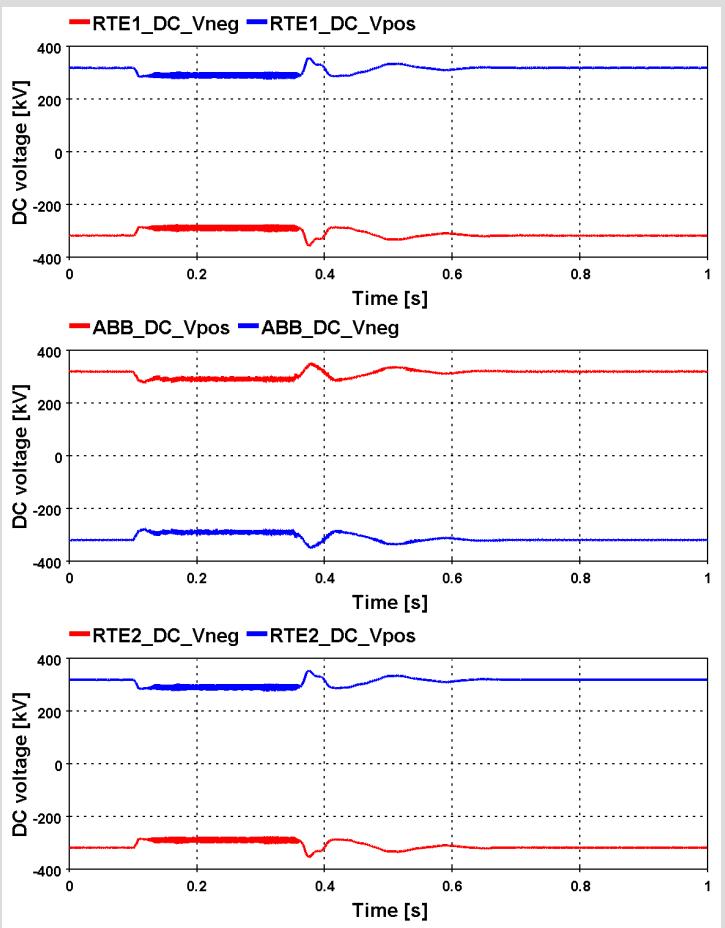
Hitachi Energy station connected as 3rd station to existing point-to-point link

- Hitachi Energy C&P hardware connected to the existing point-to-point link from the other vendor.
- 3 terminal
- Hitachi Energy station sending 1000 MW, other stations receiving 500 MW each.
- 3 phase fault on AC side near Hitachi Energy station, 20% remaining voltage for 200 ms.







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Multivendor experience - Successful interoperability tests

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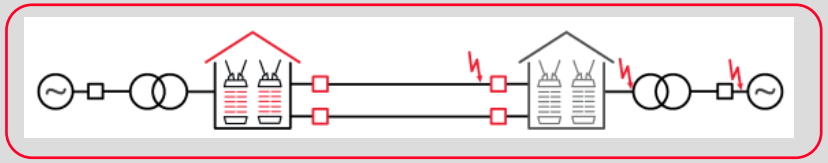
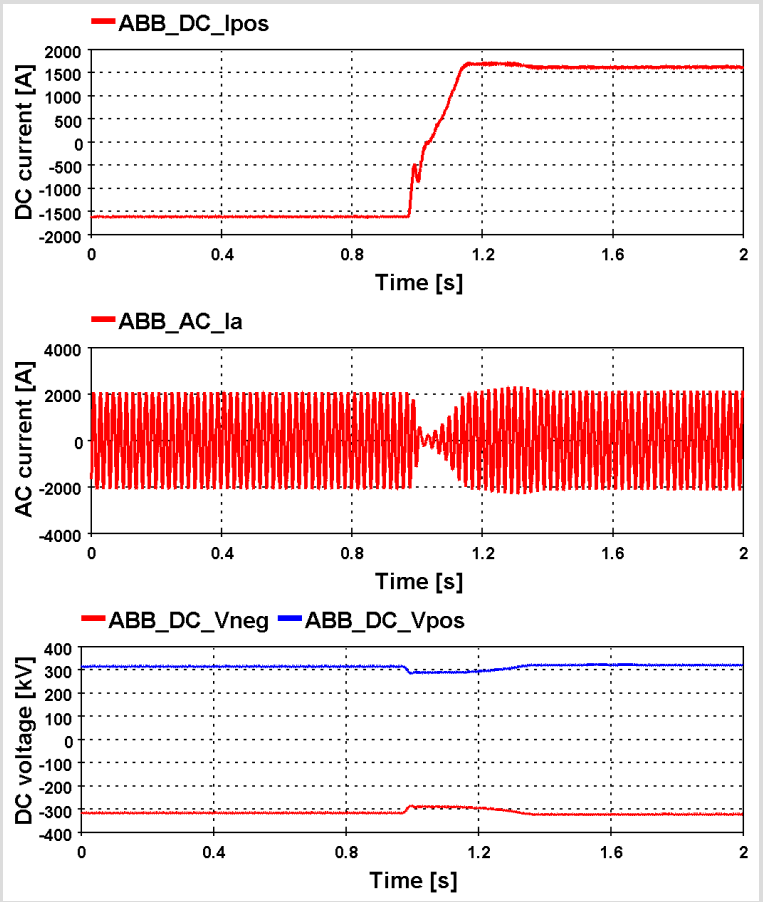
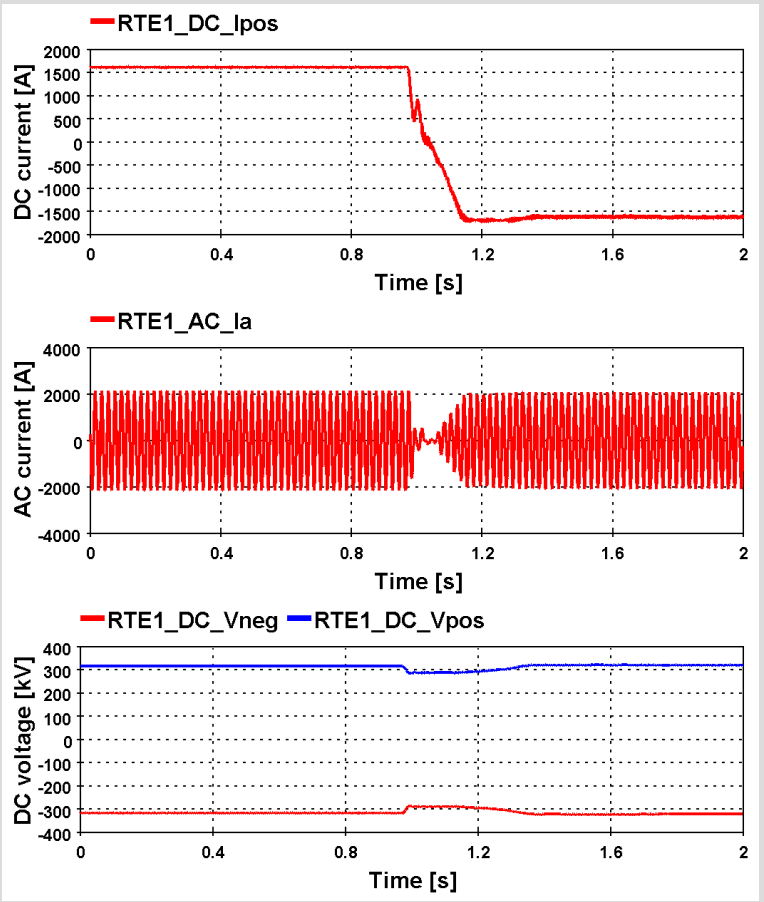
Hitachi Energy station – Another vendor

- Hitachi Energy station replica connected to one station from the other vendor.
- Point-to-point
- Fast power flow reversal (+1000 MW to -1000 MW)







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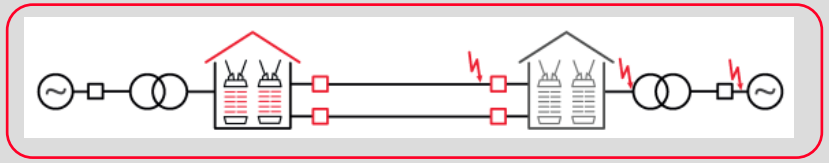
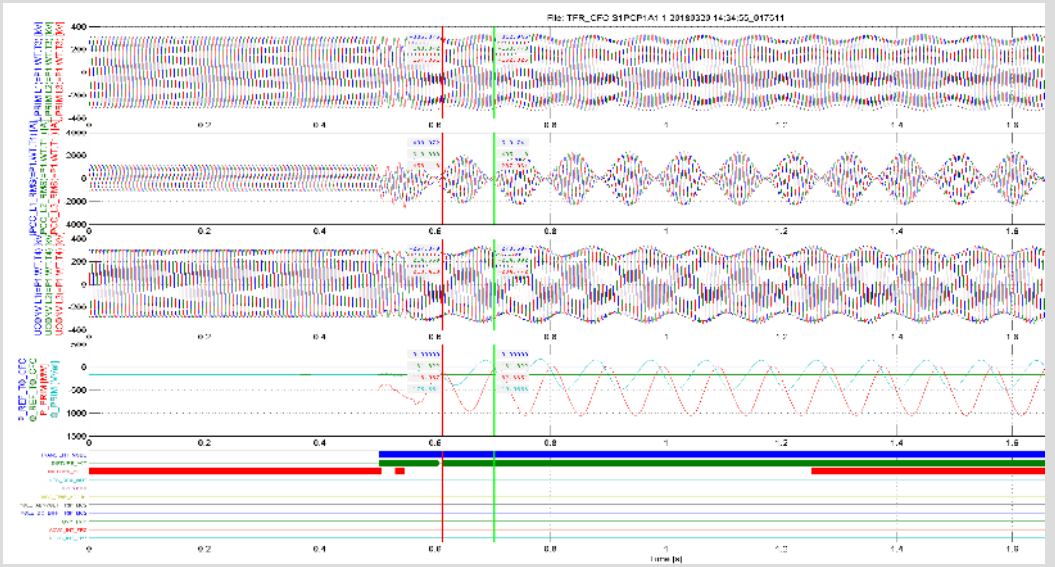
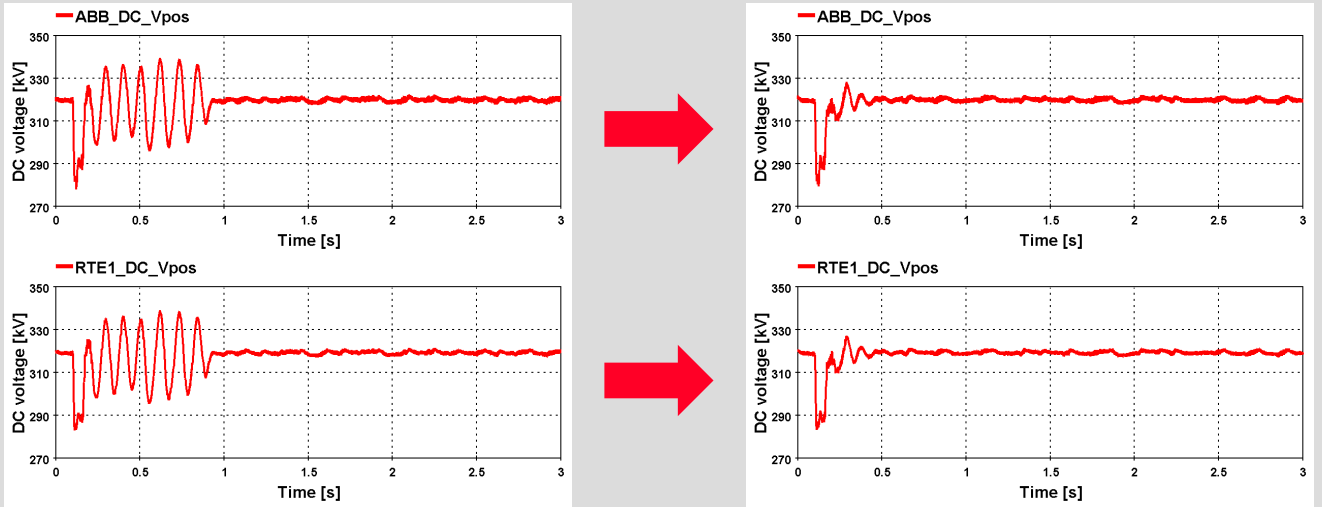
Multivendor experience – Solving interoperability issues

- Interoperability issues were solved.
- Hitachi Energy station replica connected to one station from the other vendor in point-to-point
- AC fault caused oscillations in voltage, current and power.
- Since Hitachi Energy was the only active vendor the control adaptions were made only in ABB C&P setup.







Multi-terminal HVDC system vs. AC system performance

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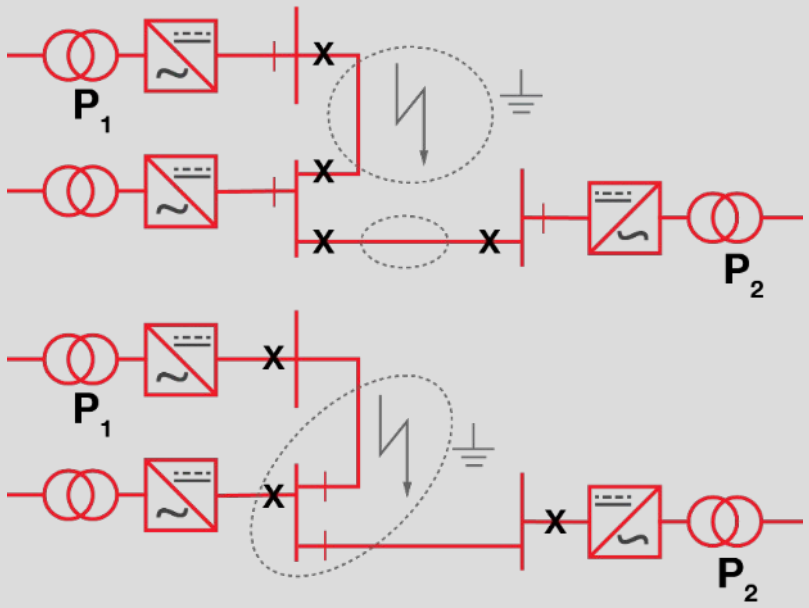
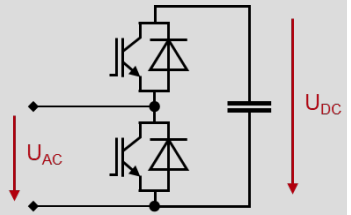
Comparison of topology options

HVDC Protection Zone (set by AC system requirements)	No	Yes
Several	HB + HVDC Breaker FB + HVDC Breaker	HB + HVDC Breaker FB + HVDC Breaker
One	HB + AC Breaker (FB not needed)	HB + HVDC Breaker FB + DC Switches

AC Voltage Support During DC Faults

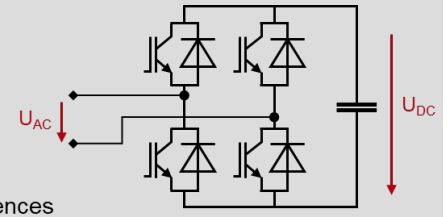


Half bridge



+ Less components
+ Less complexity
+ Lower CAPEX
+ Lower losses
+ Proven Technology
- AC circuit breaker to be opened at DC faults

Full bridge



- More components
- Higher Capex
- Higher Losses
- Limited no. of references
+ Can stay connected to the AC grid in case of DC faults
+ DC Voltage control independent of AC voltage (can be useful in OHL applications)

Hitachi Energy market position:
with Half Bridge (today solution) + HVDC Breaker combination we are able to operate in all conditions

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Meshed DC Grids

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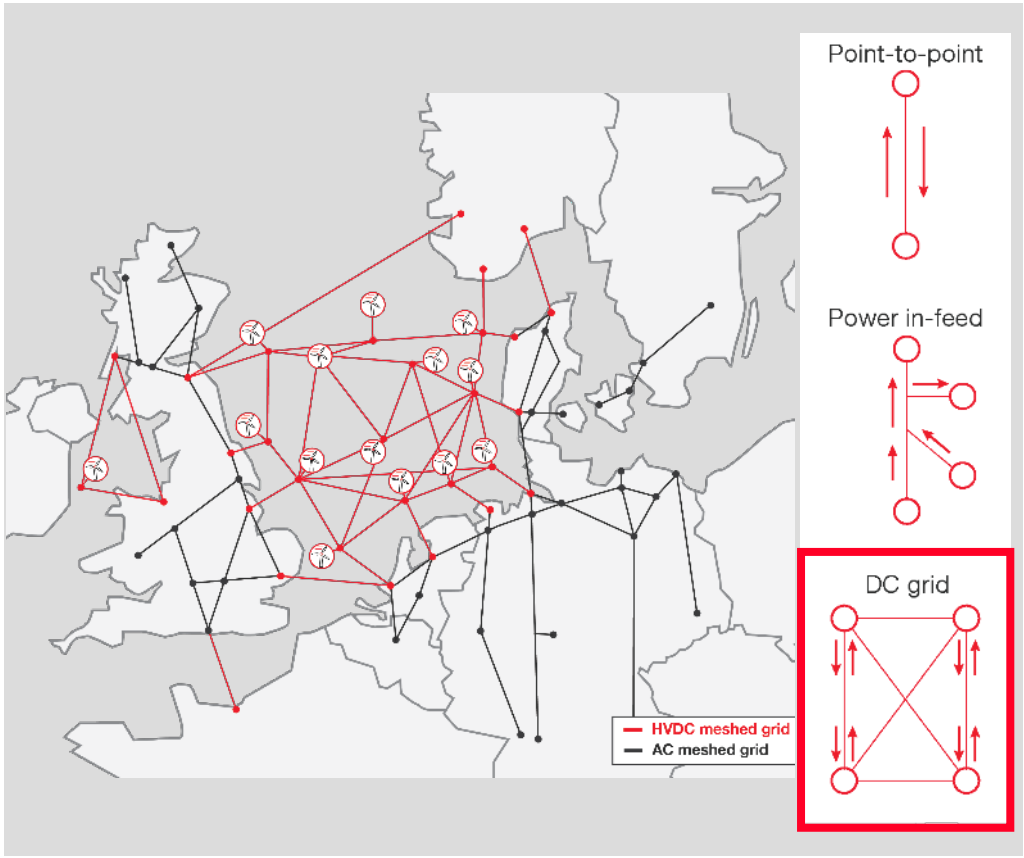
Paving the way

	What is needed?	Hitachi Energy contribution
Technology	MPI Master Controller	Realization of KriegersFlak CGS
	Enable Multiterminal concept	Caithness-Morey-Shetland & other multiterminal links
	DC Switchgear station	
	Define C&P strategies	Share through WG/publications
	DC Protection solution	DC Breaker development
Commercial and regulation	**Interoperability for expansion**	
	Technical interoperability	Active in trade associations
	DC GridCode / Ownership	
	New Procurement Process	Support industrial consultations
	New business cases definition	Support RES dev.s, O&G, TSO



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Development outline

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2009 (320kV)
Conceptual design
Component tests
Dead-tank UFD

2012 (640kV)
LCS tests
Live-tank UFD
Functionality tests

2014 (500kV)
BIGT verification tests
Plant design

2017 (535kV)
High power requirements
Standing design

2020 (350kV)
PROMOTioN

Full-scale prototype
Full control functionality
Prove of modularity
Full-scale component stresses
Product level assembly prove

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

HVDC Interoperability – Definition

Ability of a system to work **together with other systems**, now or **in the future**, **without restriction**

Needed for expansion possibility of DC Grids

System

Defined by its external interfaces and functionalities

Together with other systems

Ability to communicate and coordinate with other systems directly connected

In the future

Multi-stage (stepwise) development

Without restrictions

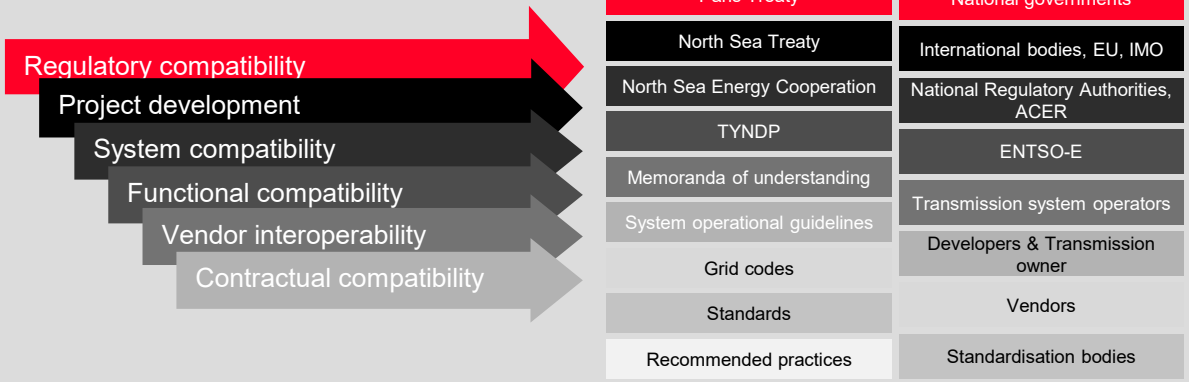
Performance according to specifications

Source: adapted from T&D Europe

Interoperability – main take-aways

Interoperability is much more than technology …

Voice of the offshore wind European Industry[1]

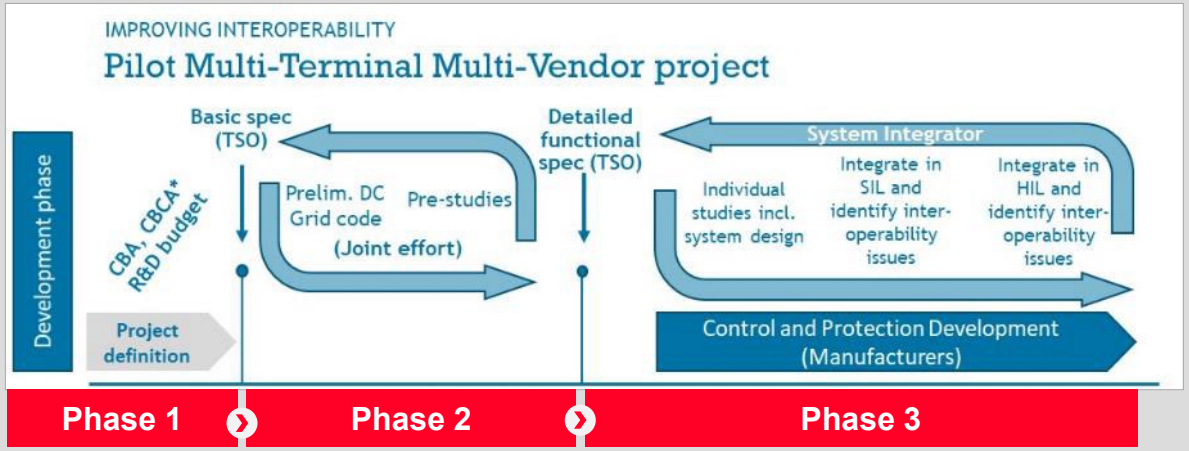


Instruments	Stakeholders
Paris Treaty	National governments
North Sea Treaty	International bodies, EU, IMO
North Sea Energy Cooperation	National Regulatory Authorities, ACER
TYNDP	ENTSO-E
Memoranda of understanding	Transmission system operators
System operational guidelines	Developers & Transmission owner
Grid codes	Vendors
Standards	Standardisation bodies
Recommended practices	

- **Technologies have reached a maturity level** calling now for an industrial scale demonstration, with special attention on **Grid Code Functional Specification** (TSO driven) and **DC Grid Control** (OEM driven)
- **A system, staged and functional approach** shall be taken to implement Interoperability **with all industrial stakeholders.**

… and pilot projects are the pathway

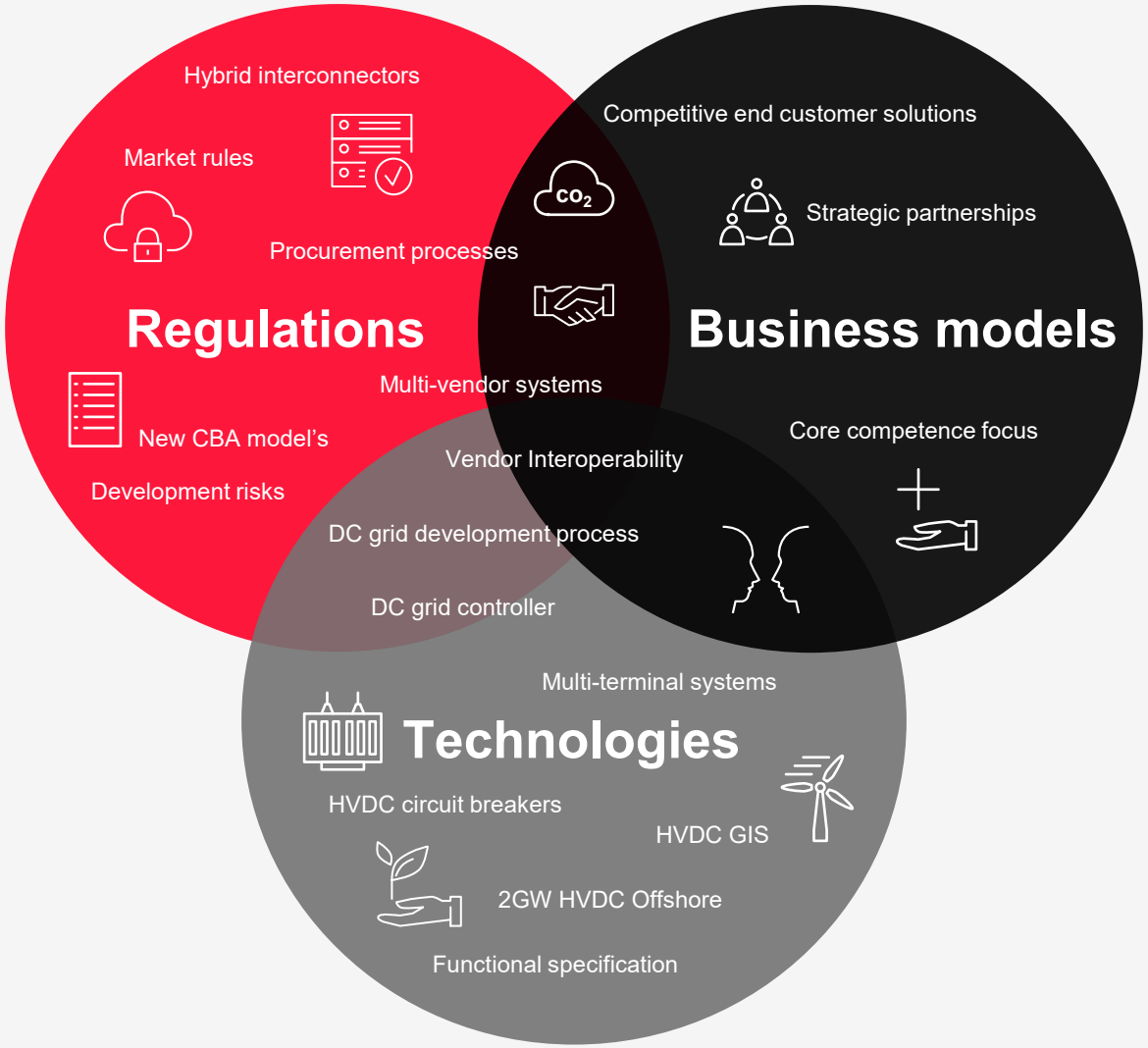
Industrial-scale project proposal made by T&D Europe and currently under discussion with ENTSO-E for EU fund application (eg. EU Green Deal)



- **Continue Hitachi Energy leading involvement** in key industrial groups on Interoperability and communicate our **position for the best technologies and approaches** (system, staged, functional)
- **Promote the importance of regulatory, legal and financial frameworks** and other **Institutional stakeholders**
- **Continue advancements of technology demonstration** through **next wave of projects**

1. Source: EU Horizon 2020 funded project PROMOTION

Industrial enablers to deliver the goals



Industrial scaling

- Rapid, consistent regulation development
- Industrial pilot projects
- Evolved business models
- Industry talent attraction

Longer term R&D needs and the research questions

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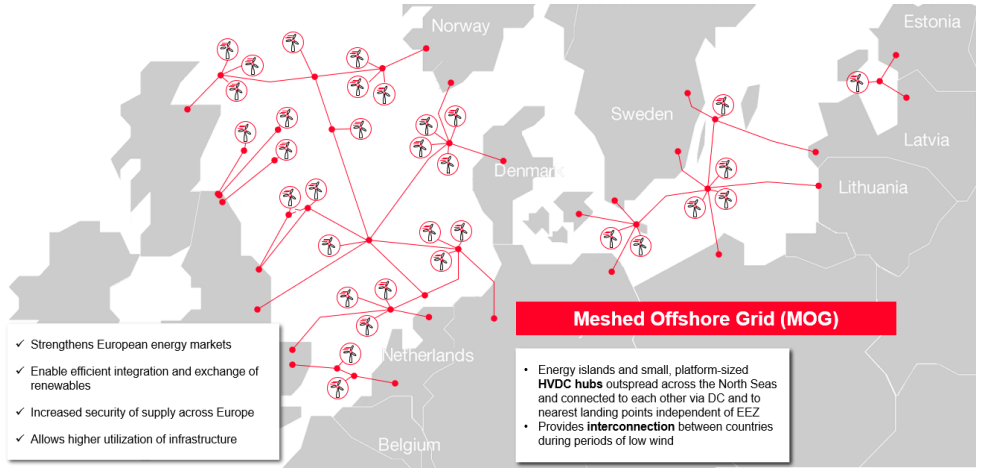
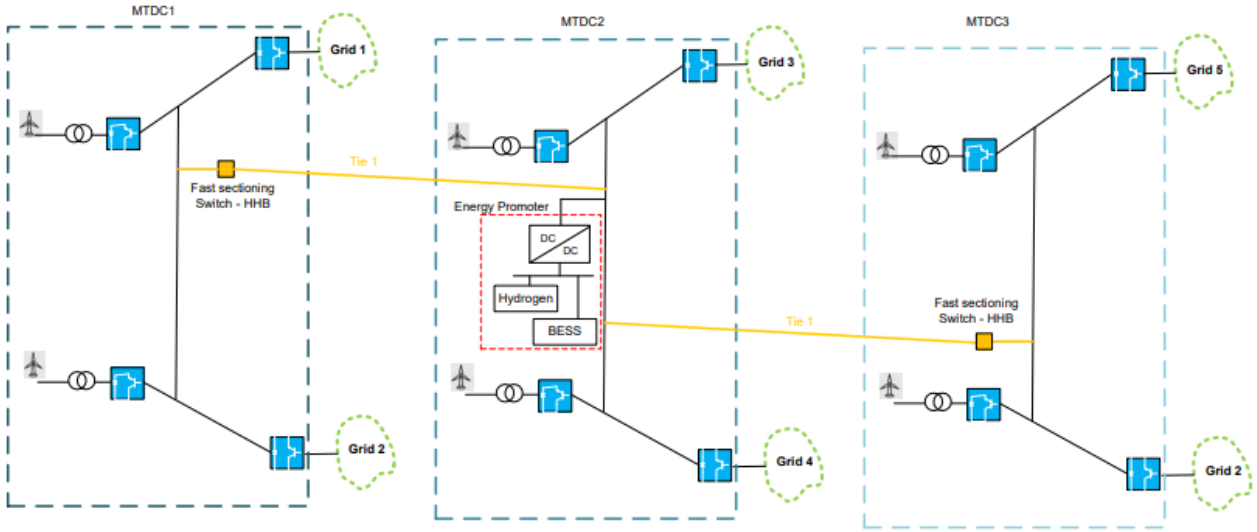
Main objective : Get the understanding of future technology needs

- How will the future MTDC layouts evolve and be, meshed and/or radial or interconnected radials with transfer switches , different voltage levels, AC ties ?
- How many Power Flow Controllers and DC-DC or DC-DC-x converters will be needed ?
- What are the energy storage needs, type of storage, locations centralized or distributed and its benefits in GFC and resilience ?





cigre SC B4: DC systems and power electronics Newsletter

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