HOW TO DE-RISK LARGE-SCALE MULTI-VENDOR HVDC SYSTEMS, LESSONS FROM THE NORTH SEA WIND POWER HUB PROJECT

SPEAKERS

Laurids Dall
Senior Power System Engineer

Ming Cai
HVDC Expert

Sébastien Dennetière
Senior HVDC Expert

Markus Vor dem Berge
Director of Power Electronics & Studies

AGENDA

ENERGINET
Systemansvar

DE-RISKING OF OFFSHORE WIND POWER HUB PROJECTS

8/2-2022

CONTENT

1. Introduction to offshore projects
2. The electrical design
3. Considerations of de-risking the electrical operation

THE ELECTRICAL SYSTEMS OF OFFSHORE HUBS

Due to the size and distance to the public power system, the operation of the electrical infrastructure on the Energy Island can largely be considered an isolated independent offshore system.

In this system large-scale wind power plants, HVDC systems, HVAC systems and potentially consumption plants be connected tightly together.

There is no existing well-established system to absorb the small or large disturbances occuring in the electrical operation on the Island.

A primary conssequence is that the offshore systems alone must form and stabilize the grid which they are a part of. Each HVDC system and wind power system is interdependant on the operation of the other.

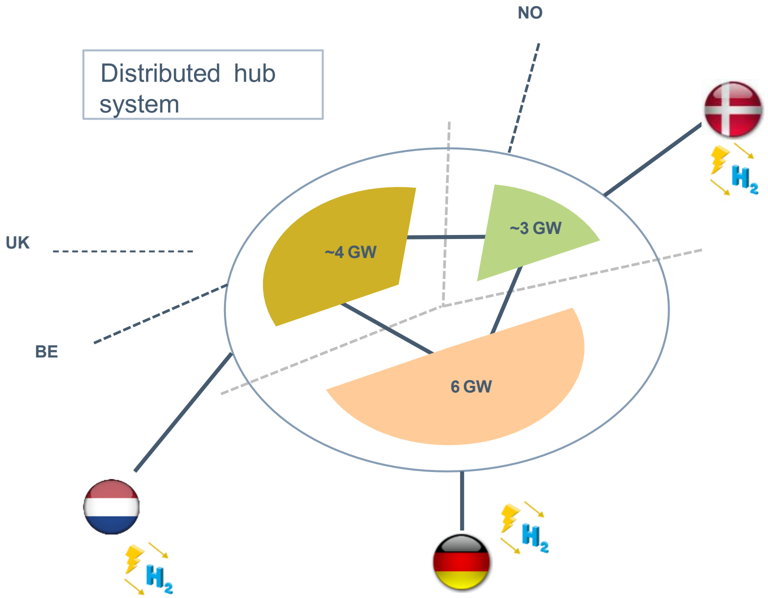
NORTH SEA WIND POWER HUB CONSORTIUM

ENERGINET (Denmark)	Danish transmission system operator working for a green, reliable and sustainable energy supply of tomorrow
gasunie (Netherlands)	European energy infrastructure company serving the public interest by providing integrated infrastructure services
TenneT (Germany, Netherlands)	Dutch-German electricity TSO and one of Europe's major investors in national and cross-border grid connections on land and at sea in order to establish the energy transition

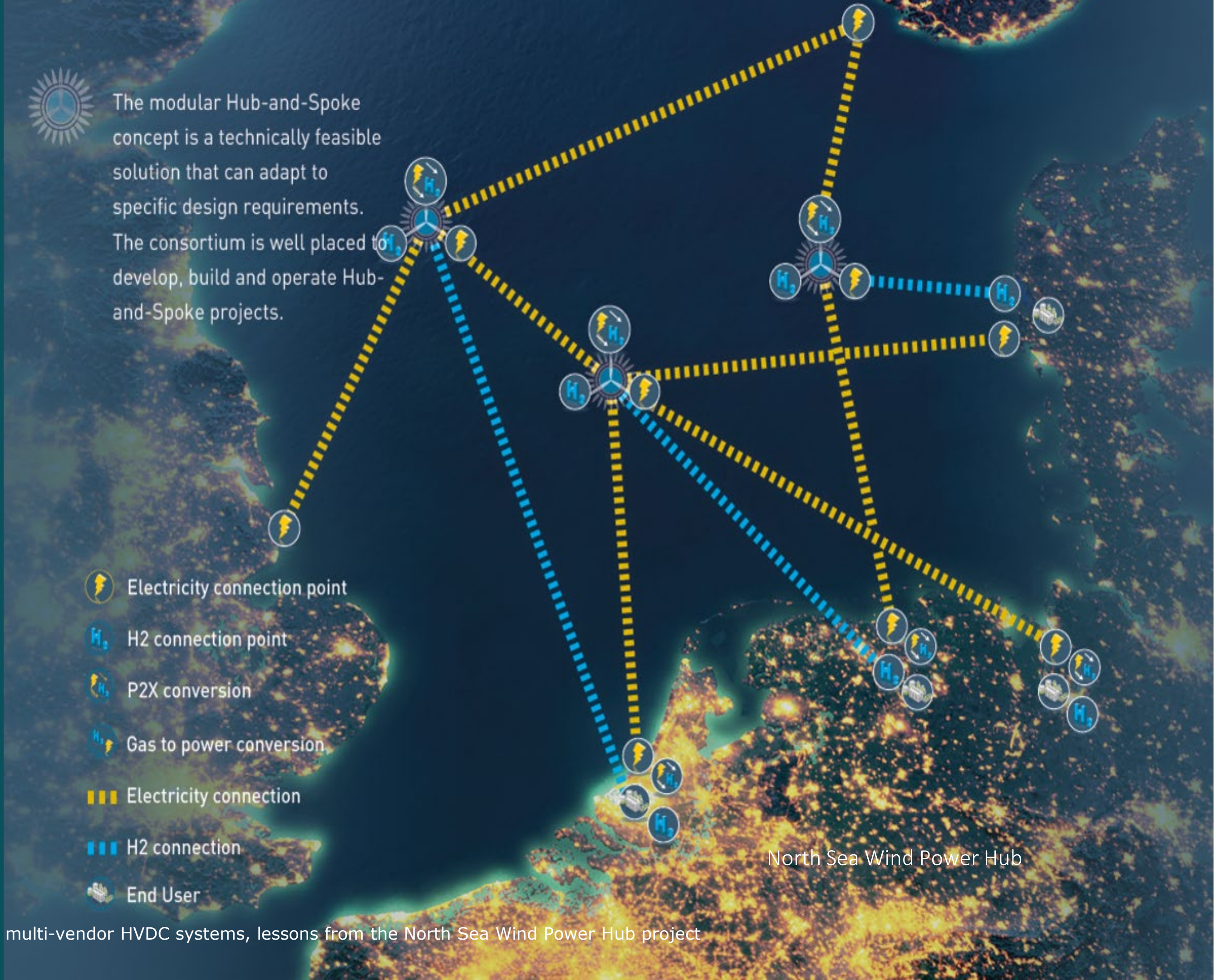
Vision of NSWPH Consortium

- To reach climate neutrality in 2050, significant (300 GW) offshore wind capacity needs to be built
- We consider it our social responsibility to pro-actively facilitate affordable and secure connection and integration of this vast amount of energy
- This requires a series of hub-and-spoke projects, with the ambition to realise the first hub in the early 2030s

Co-financed by the Connecting Europe Facility of the European Union



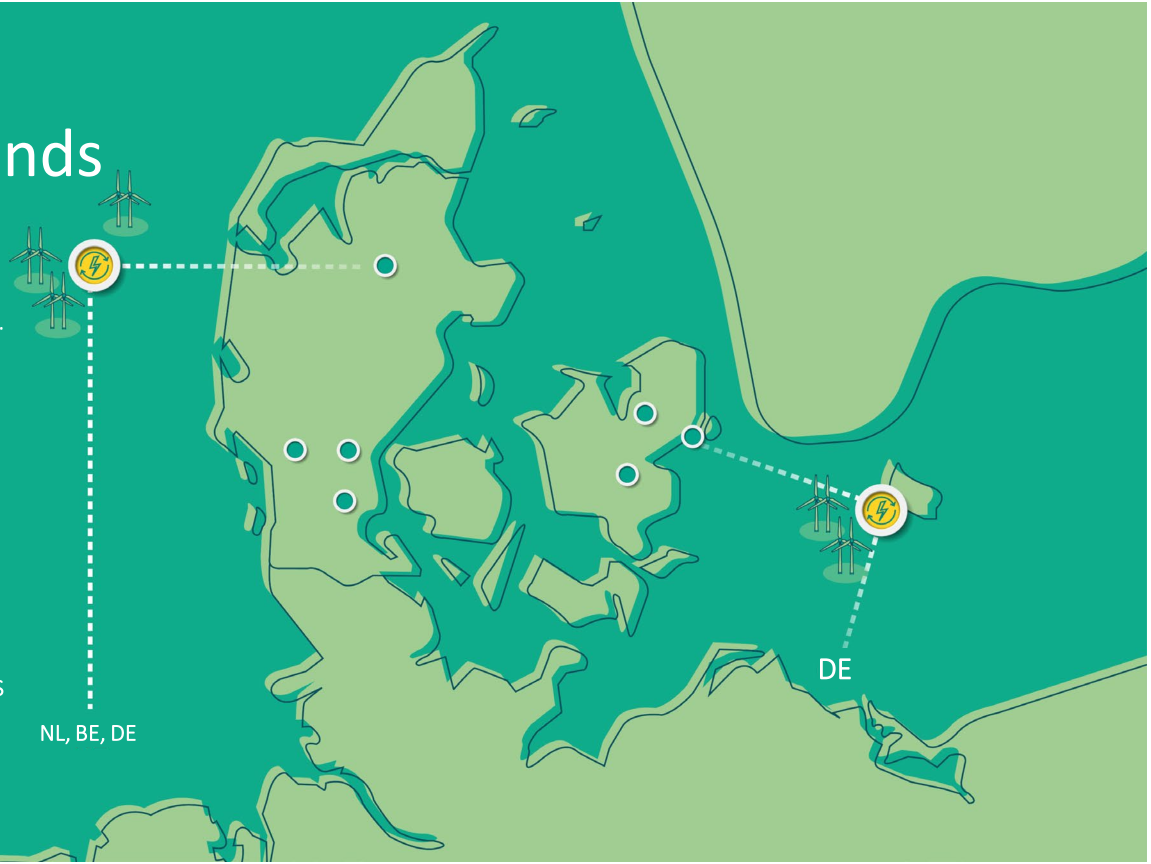
A POSSIBLE VERSION OF THE FUTURE



Energy Islands

The North Sea:
3 GW offshore wind by 2033, later at least 10 GW.

The Baltic Sea:
3 GW offshore wind by 2030.

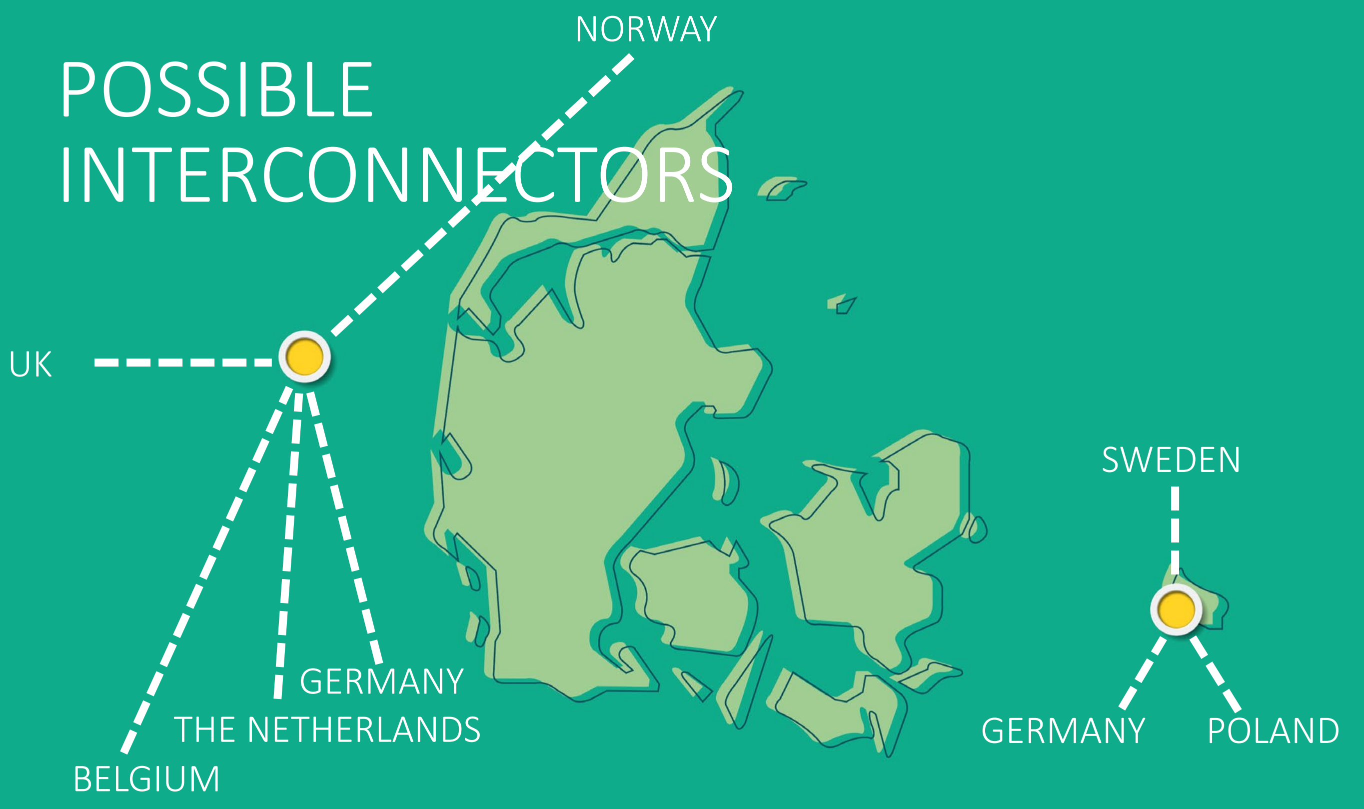


NEW OFFSHORE WIND FARMS

ENERGY ISLAND

ONSHORE CONNECTIONS, ALTERNATIVES

POSSIBLE INTERCONNECTORS



23 November 2021

Denmark and Belgium to connect energy islands with undersea cable

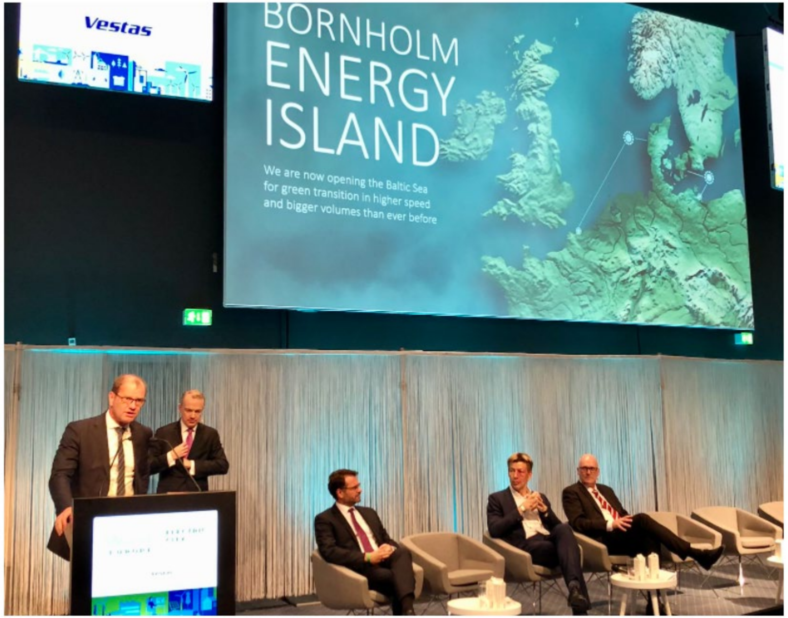
© ELIA

Grid operators Elia (BE) and Energinet (DK) are to collaborate further on the creation of a world first: the first undersea connection between two energy islands, exchanging power between two countries and bringing energy from offshore wind farms on land. Danish Climate and Energy Minister, Dan Jørgensen and the Belgian Energy Minister Tinne van der Straeten signed an agreement to build interconnector between their energy islands at WindEurope's annual event Electric City. German State Secretary at the Ministry for Economic Affairs and Energy Andreas Feicht also signed an agreement with the Danish Minister to connect the Danish island of Bornholm to the German grid.

https://windeurope.org/newsroom/news/denmark-and-belgium-to-connect-energy-islands-with-undersea-cable/

23.11.2021 | PRESSEMITTEILUNG

Bornholm Energy Island: 50Hertz and Energinet sign cooperation agreement for offshore hub in Baltic Sea



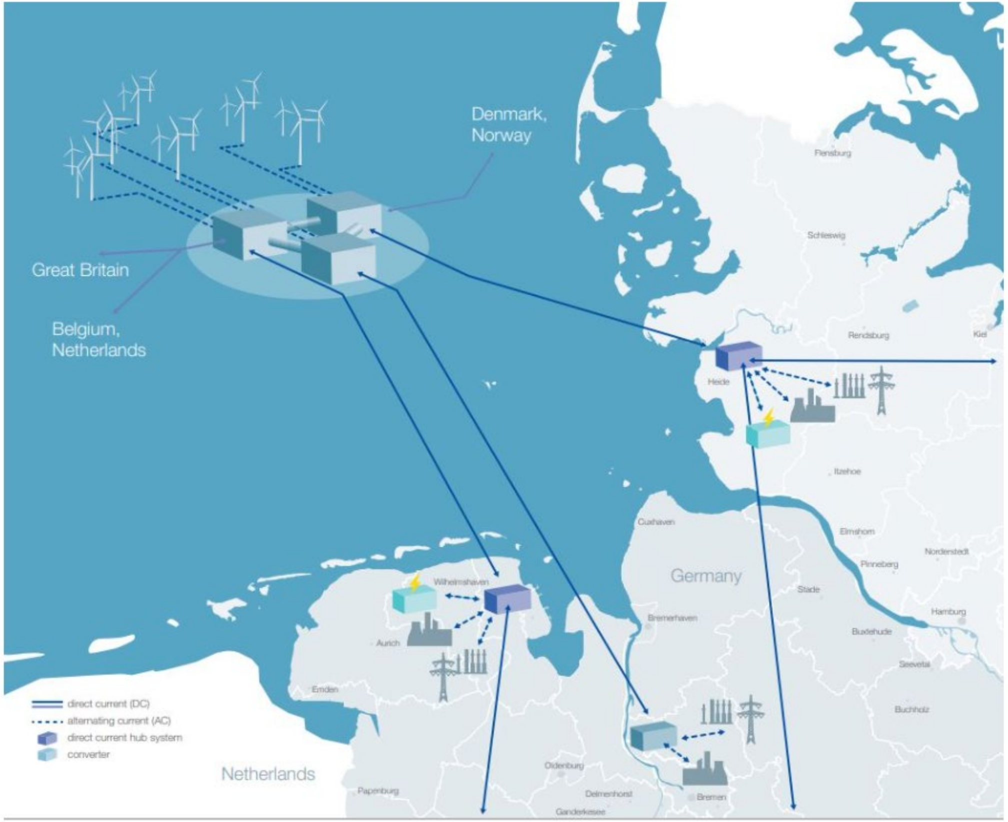
50Hertz CEO Stefan Kapferer speaks at the signing of the contract at the windEurope conference. On the podium State Secretary Andreas Feicht, Thomas Egebo (Energinet) and Chris Peeters (Elia Group).

https://www.50hertz.com/en/News/FullarticleNewsof50Hertz/11599/bornholm-energy-island-50hertz-and-energinet-sign-cooperation-agreement-for-offshore-hub-in-baltic-sea

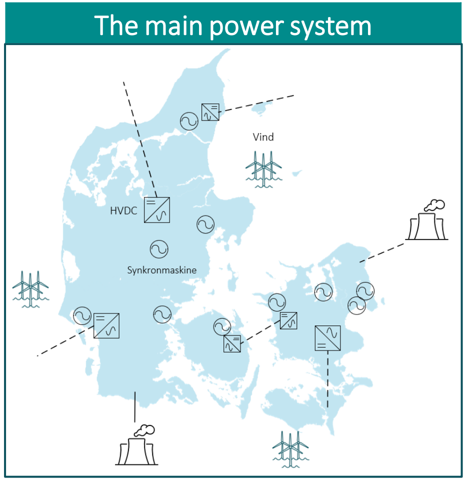
TenneT

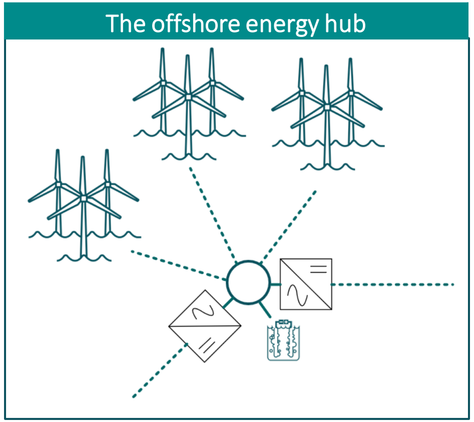
ENERGINET

November 2021



LanWin hub; Image: TenneT





CONTROL AND STABILITY OF THE OFFSHORE HUBS

The energy hub can be defined by the following characteristics:

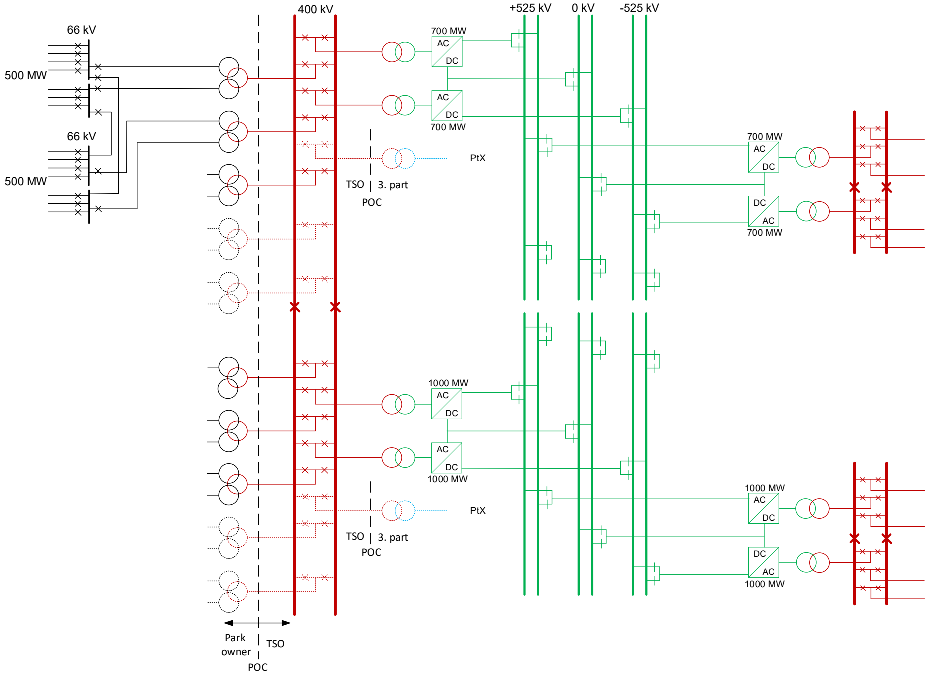
1. An independent electrical system
2. A 100 % power electronic based power system
3. A multi-vendor multi-stakeholder environment
4. A multi-purpose system (e.g. generation, interconnector capacity and future power-to-x innovation)
5. A modular and expandable offshore power system

Why does this lead to increased risk of control and stability related issues:

1. There is no or very limited national or international experience in this type of systems
2. There are no standards for securing stability and interoperability in this type of systems
3. Depends on development of new methods and products
4. Solving stability related issues is not only a technical problem, but also a legal problem of contractual obligations and the issue of sharing IP protected information between stakeholders

The novelty in connecting multiple offshore wind parks together with multiple HVDC systems leads to increased risk for stability related issues

MULTI-VENDOR MULTI-PURPOSE MULTI-TERMINAL HVDC

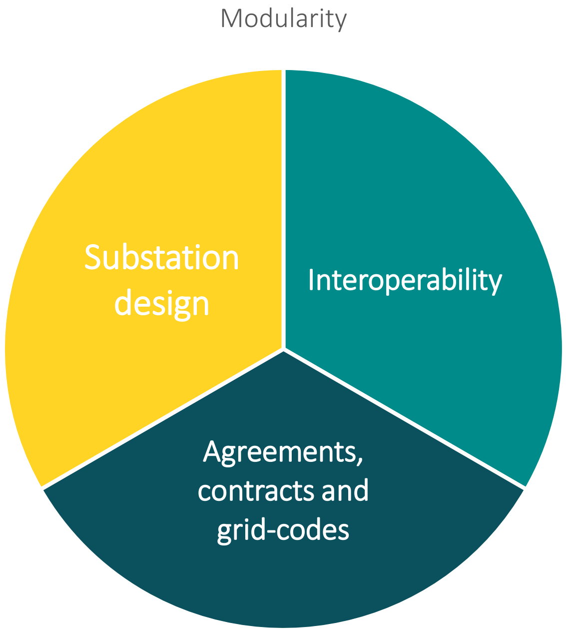


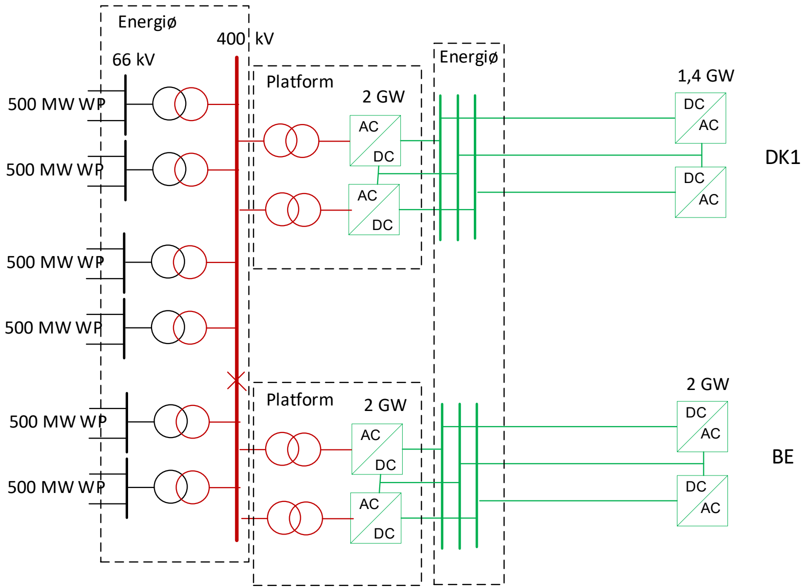
Novelties which require development and increases risk:

1. Functional requirements and tuning of parallel grid-forming converters connected on the AC side
2. Detecting and mitigating adverse control interactions between power electronics
3. Control and protection of multi-terminal HVDC grids
4. Multi-vendor interoperability, including:
5. Aligning and sharing IP protected models and data between developers, vendors and TSO

MODULARITY OF THE DESIGN

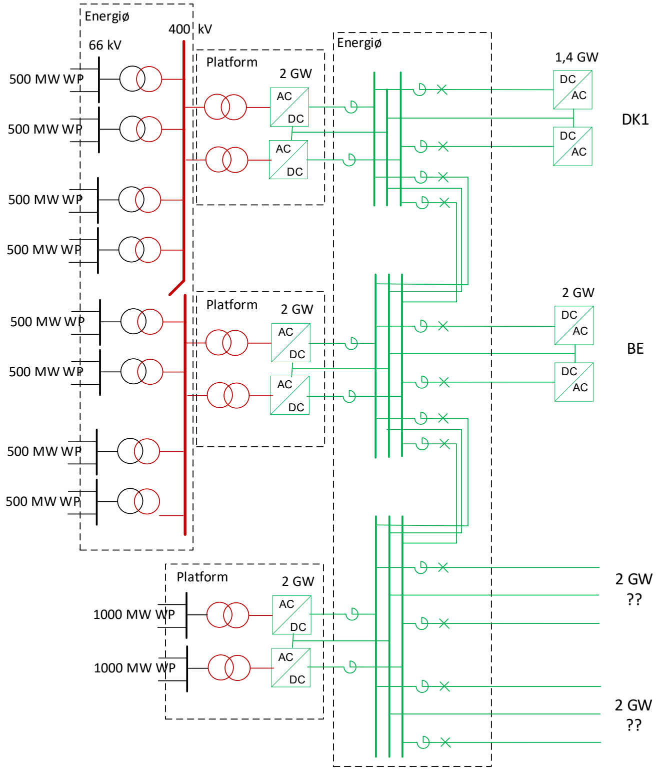
The offshore hubs should be expandable





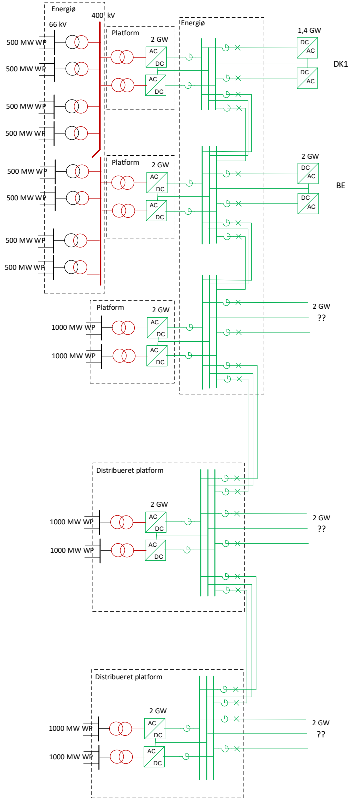
Phase 1

- 3 GW wind capacity
- 3,4 GW transmission capacity
- AC connection of HVDC links
- HVDC on platforms near to the energy island
- 400 kV AC GIS busbar on the island
- 525 kV DC GIS busbar on the island
- No DC breakers or DC reactors installed



Phase 2

- 6 GW wind capacity
- 7,4 GW transmission capacity
- Multi-terminal DC grid
  - 400 kV substation sectionalized
- HVDC on platforms:
  - Three 2 GW platforms near to the island
- 400 kV AC GIS busbar on the island for 4 GW wind power
- Cables from windfarms:
  - To the island for 4 GW wind
  - Directly to HVDC platforms for 2 GW wind
- 525 kV DC GIS busbar, DC reactors and DC breakers
  - On the island for 6 GW wind



Phase 3

- 10 GW wind capacity
- 11,4 GW transmission capacity
- Multi-terminal DC grid
  - 400 kV substation sectionalized
- HVDC on platforms:
  - Three 2 GW platforms near to the island
  - Two 2 GW distributed platforms
- Cables from windfarms:
  - To the island for 4 GW wind
  - Directly to HVDC platforms for 6 GW wind
- 525 kV DC GIS busbar, DC reactors and DC breakers
  - On the island for 6 GW wind
  - On the distributed platforms for 4 GW wind

SYSTEM INTEGRATION

ENSURING HUB STABILITY

MODULARITY AND INTEROPERABILITY

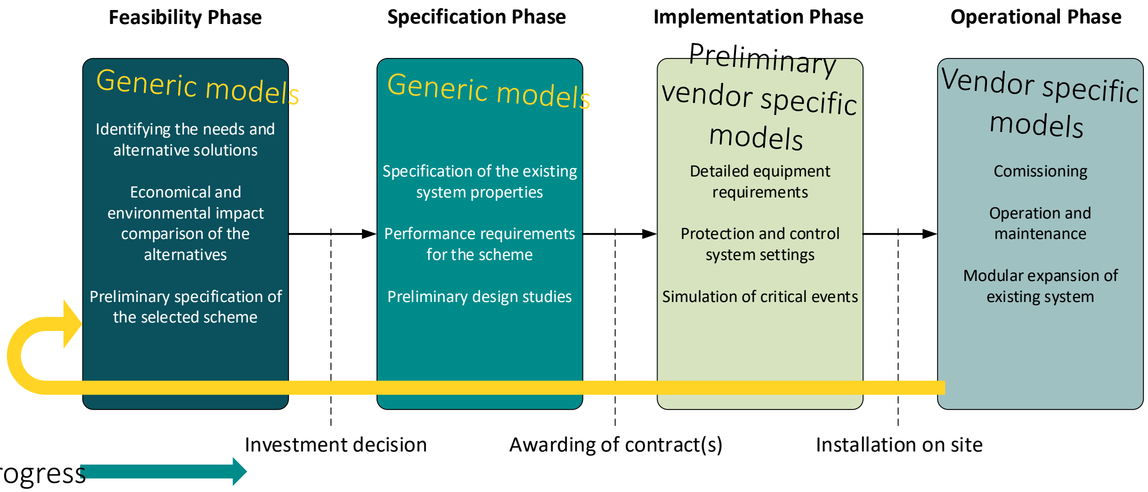
NORMAL OPERATION

MODEL AND DATA EXCHANGE FRAMEWORK

GRID CODES AND CONNECTION PROCESSES

PROJECT PHASES

Seen from an electrical study and analysis point of view



MAIN STABILITY RELATED RISKS

CAUSE

Limited national and international experience in design and operation of offshore hybrid projects and multi-vendor multi-terminal HVDC systems

Vendor technology and data is unknown in the feasibility and planning phase

Unclear or unknown expectation and requirements to future expandability or connection of novel technologies, such as Power-to-X.

Stability related issues cannot be properly detected due to insufficient model accuracy and poor model availability across stakeholders (TSO, WPP owner, HVDC vendor)

INCIDENT

Preliminary stability analysis and assumptions is erroneous and leads to incomplete or incorrect functional requirements and design parameters for control and protection

Design of substations, control systems and protection cannot be smoothly adapted to connect future systems

Control interactions or short-circuits leads to cascading trips of wind power plants or HVDC systems

EFFECT

Delay in the implementation or operational phase

Increased capital cost due to re-design and re-configuration of systems

Legal and contractual disputes between stakeholders

Loss of revenue due to long-term outtage or curtailment of prouction and transmission assets

Violation of maximum loss of infeed leads to onshore system instability causing local brown-outs or black-out

INTERNATIONAL EXPERIENCE

What is being done to de-risk international projects concerning HVDC and wind power integration?

DE-RISKING OF NATIONAL AND INTERNATIONAL PROJECTS

20/07386-34 RTEi_De-risking_NSWPH_feasibility_report_HIL_final_Rev1.pdf
https://esdh.si.energinet.local/locator.aspx?name=Common.Details.Navigate&module=Document&subtype=2&recno=4852740

MULTI-VENDOR HVDC EXPERIENCE

20/07386-11 Experiences with multi-vendor offshore HVDC systems - Meeting with Kamran Sharifabadi, Equinor
https://esdh.si.energinet.local/locator.aspx?name=Common.Details.Navigate&module=Document&subtype=2&recno=4732070

DE-RISKING OF HVDC PROJECTS IN THE UK

20/07386-23 Experiences from The National HVDC centre in UK - designing an expandable multi-terminal HVDC system
https://esdh.si.energinet.local/locator.aspx?name=Common.Details.Navigate&module=Document&subtype=2&recno=4777632

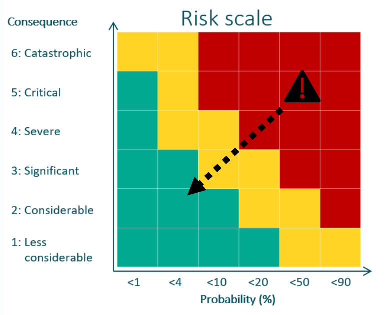
EXPERIENCE WITH HVDC CONNECTED OFFSHORE WIND POWER PLANTS

20/07386-22 German experiences with HVDC connected wind.docx
https://esdh.si.energinet.local/locator.aspx?name=Common.Details.Navigate&module=Document&subtype=2&recno=4777629

REDUCING RISK: PROBABILITY AND CONSEQUENCE

REDUCING THE PROBABILITY OF INSTABILITY

- Well-prepared functional requirements
- High model accuary
- Performing detailed studies in cooperation with stakeholders



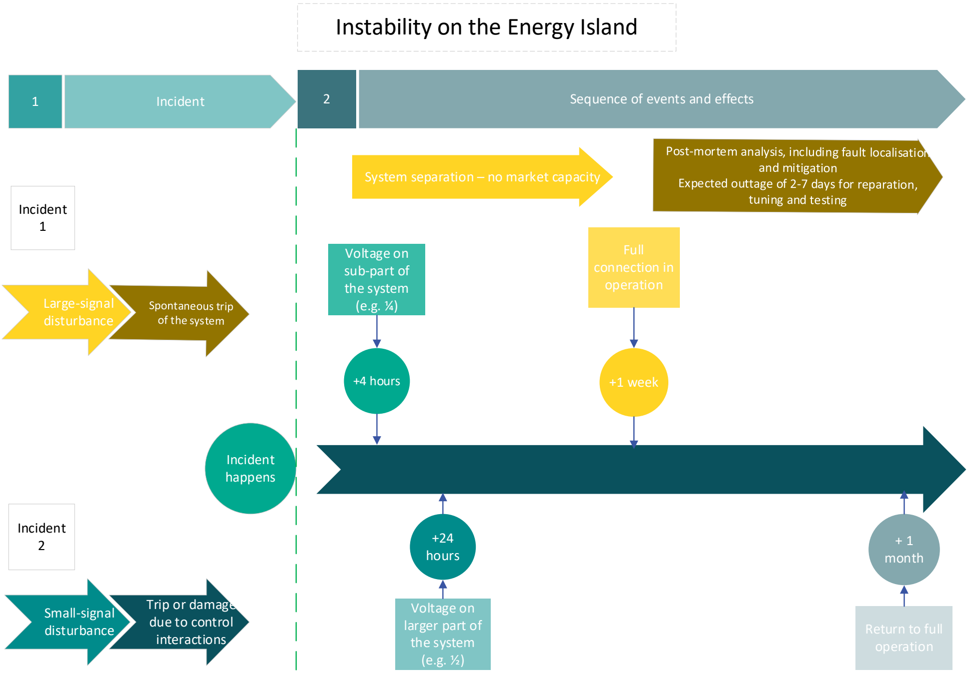
REDUCING THE CONSEQUENCE – MINIMIZE OUTTAGE TIME

- Efficient troubleshooting and error detection
- Fast proces for updating and re-distributing models
- Efficient implementation of solutions (e.g. control tuning)

Risk price = Probability · Consequence

QUANTIFICATION OF INSTABILITY RISKS

Estimating the consequences of instability (outtage time and reduced availability)



How to quantify the cost of stability related risks?

Some thoughts:

Two main type of incidents which can lead to instability and trip of systems:

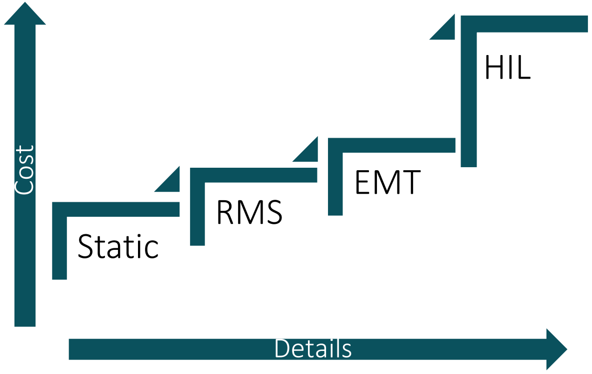
- Large-signal disturbances
- Small-signal disturbances

What is the economical conseqeuence of these incidents?

- Estimated outtage time
- Reduced market capacity
- Curtailment of production facilities

TOOLS AND MODEL FOR DE-RISKING

Analysis environment



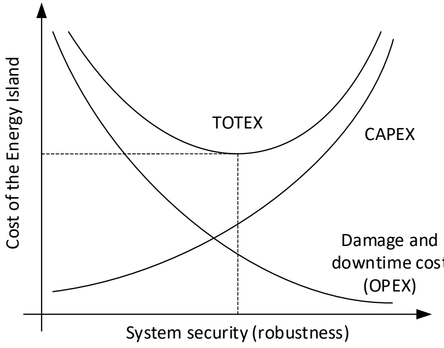
Desktop

SIL & HIL

Ambition

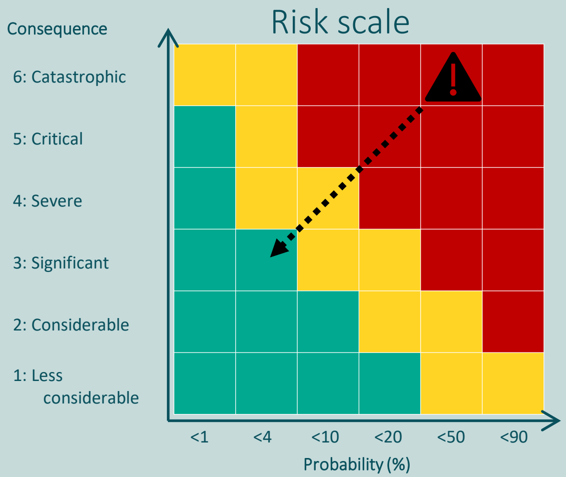
- Update the existing
- Introduce the new
- Preparing for multiple version of the future

How to de-risk in a cost-effective way?



WHAT CAN REDUCE THE PROBABILITY AND THE CONSEQUENCE?

De-risking of the electrical operation

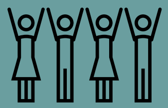


HIGH QUALITY OFFLINE MODELS AND CLEAR PROCESSES FOR SHARING AMONG STAKEHOLDERS

CLEAR COOPERATION FRAMEWORK AND AGREEMENTS

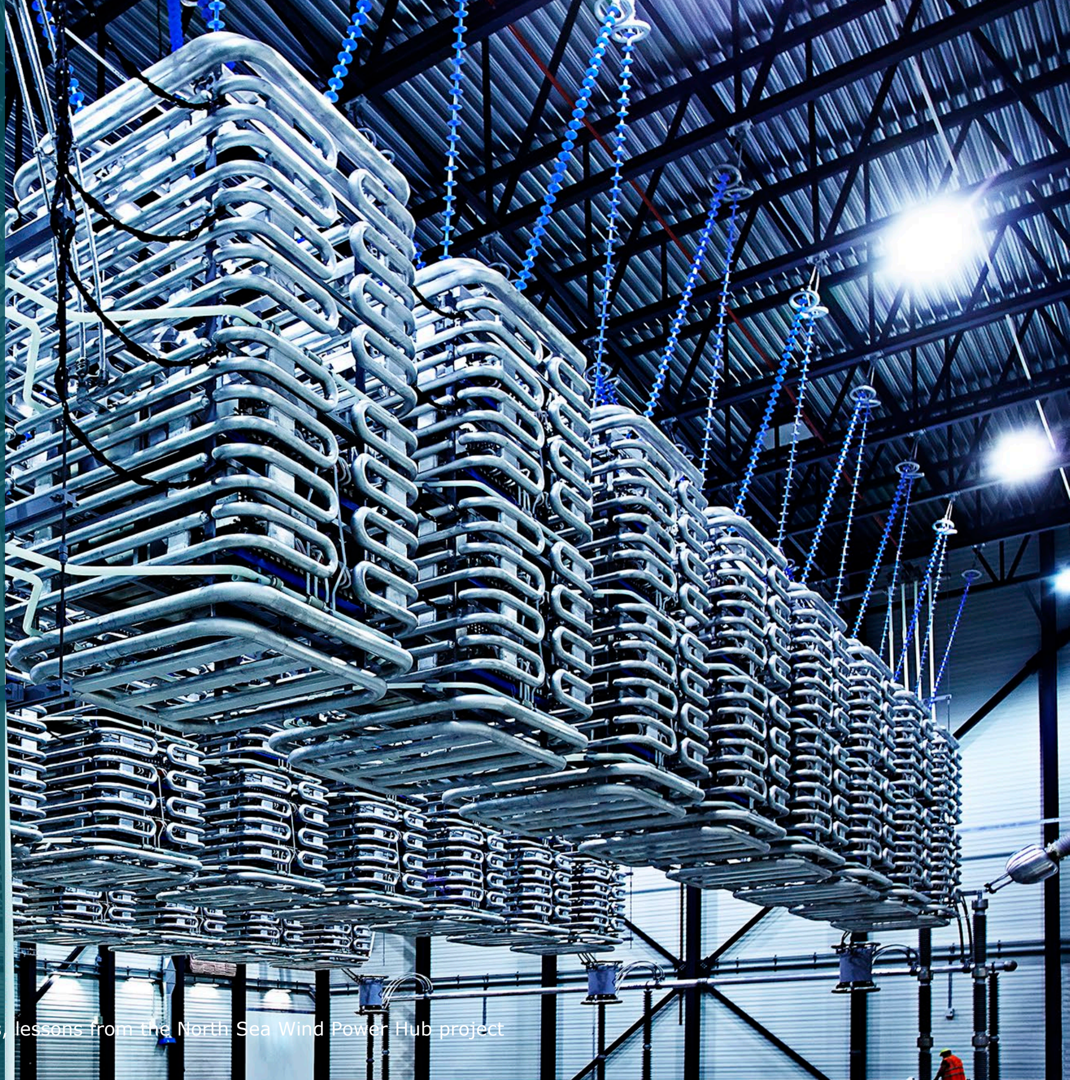
USE OF C&P REPLICAS AND HIL TESTING?

INTERNATIONAL ALIGNMENT AND COOPERATION



Are control and protection replicas and HIL testing a feasible way of de-risking the first offshore hubs

?

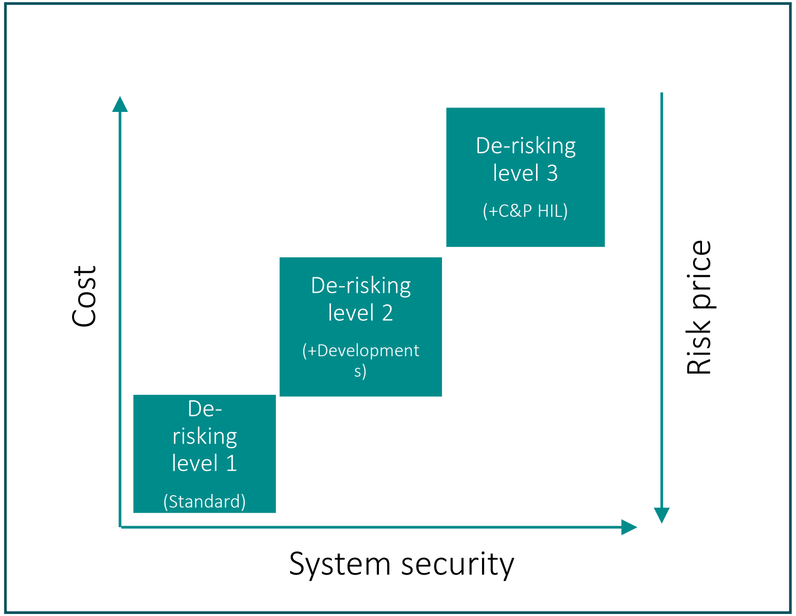


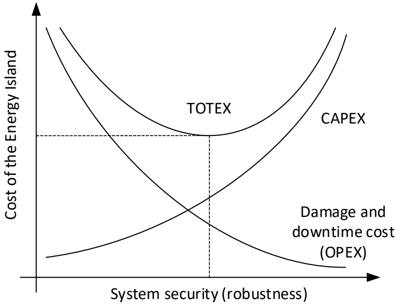
IS HIL TESTING WITH C&P REPLICAS A FEASIBLE METHOD FOR DE-RISKING: DO THE PROS OUTWEIGH THE CONS?

Arguments for HIL with C&P replica
Increased risk in hybrid projects (wind, HVDC, future PtX)
Multi-vendor handling
Multi-infeed (multiple systems in parallel)
Lack of standards for novel technologies
Offshore maintenance training and preparation

Arguments against
Expensive compared to offline models (equipment and ressources)
Lack of experience and human resources in dealing with C&P replicas and laboratories
In theory offline EMT models should be sufficiently accurate
Many improvements to be gained in field of offline EMT models to make it competitive
Many studies can be done in parallel with offline EMT
Simplifications are needed to HIL and numerical problems may occur

IS C&P REPLICAS AND HIL TESTING WORTH THE INVESTMENT?





Risk price of instability with standard methods of de-risking

Risk price (Mitigation Level 1) = Probability (Mitigation Level 1) · Consequence (Mitigation Level 1) + Cost (Mitigation Level 1)

Risk price of instability with development of new requirements and methods

Risk price (Mitigation Level 2) = Probability (Mitigation Level 2) · Consequence (Mitigation Level 2) + Cost (Mitigation Level 2)

Risk price of instability with development of new requirements and methods, including C&P replica and HIL

Risk price (Mitigation Level 3) = Probability (Mitigation Level 3) · Consequence (Mitigation Level 3) + Cost (Mitigation Level 3)

MAJOR DEVELOPMENT ACTIVITIES FOR THE OFFSHORE HUBS

Implementation of new offline model methodologies and requirements

Functional requirements for grid-forming control

Multi-terminal HVDC control and protection

Master controller design for AC and DC coupled modes

Control and protection replicas and HIL simulation

INTRODUCTION

INTRODUCTION

Increasing penetration of power electronics devices (PEDs) has been challenging grid stability and reliability

Wind

Solar

BESS*

HVDC

- Complex Control & Protection (C&P) function implementation
- Disturbances in converter-dominated systems have been continually observed and documented (e.g., USA, UK, Australia, China, etc.)

*Source: RECHARGE – Global news and intelligence for the Energy Transition.
https://www.rechargenews.com/wind/ge-seals-its-largest-us-battery-energy-storage-system-order/2-1-678193

INTRODUCTION

Example of a disturbance event in a converter-dominated system

- Time and location: May 9, 2021, near Odessa, Texas
- Event: a 1phg fault occurred on a generator step-up transformer and was cleared within 3 cycles. Voltage in the affected area recovered quickly following fault clearance.
- Consequence: active power reduction observed at solar PV and wind plants caused by abnormal response to fault

Table ES.1: Reductions of Output by Unit Type

Plant Type	Reduction [MW]
Combined Cycle Plant	192
Solar PV Plants	1,112
Wind Plants	36
Total	**1,340**

Table 1.1: Causes of Reduction

Cause of Reduction	Reduction [MW]
PLL Loss of Synchronism	389
Inverter AC Overvoltage	269
Momentary Cessation	153
Feeder AC Overvoltage	147
Unknown	51
Inverter Underfrequency	48
Not Analyzed	34
Feeder Underfrequency	21

The Electric Reliability Council of Texas (ERCOT) conducted investigations following this event

Introduction

Key findings by Electric Reliability Council of Texas (ERCOT)

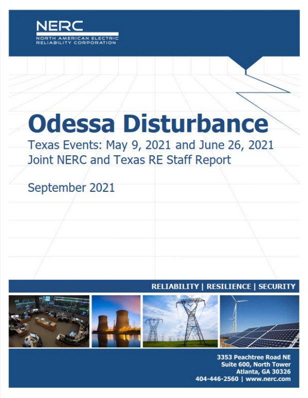
Key Finding
Solar PV plants continue to trip on PLL loss of synchronism, and these issues are not being properly mitigated. TOs, in coordination with their RC, BA, TP, and PC, are not establishing interconnection requirements to prohibit plants from tripping on PLL loss of synchronism. This form of tripping is not addressed in PRC-024-3 but it is the most significant cause of solar PV reduction in this event. This has led to unreliable performance of a number of large BES solar PV resources that lack sufficient ride-through capability to support the BPS for normal BPS fault events. This reliability issue is persistent, growing in the number of resources prone to this issue, not being mitigated appropriately, and warrants mitigating actions to address. The NERC RSTC should direct the NERC IRPWG to produce a SAR to mitigate this issue effectively.

Key Finding
Plant-level controller interactions with inverter response after fault events continue to be an issue for BPS solar PV facilities. These two layers of controls are not properly tuned with each other and are resulting in unreliable performance of these resources once connected to the BPS. Furthermore, these interactions are not properly being identified in the interconnection study process.

Key Finding
Multiple solar PV plants tripped on inverter terminal or feeder-level protection caused by inverter and plant-level controls driving voltage conditions above trip settings to some degree. The electrical response of the facility is based solely on the logic programmed into the inverter and plant-level controls. These issues should have been identified during interconnection studies, yet the plant was able to connect in an unreliable manner.

***Previous incidents reported by ERO in California**

- Blue Cut Fire disturbance (Aug. 16, 2016)
- Canyon 2 Fire disturbance (Oct. 9, 2017)
- Palmdale Roost and Angeles Forest disturbance (Apr. 20 and May 11, 2018)
- San Fernando disturbance (July 7, 2020)



https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf

Introduction

The development and integration of large-scale offshore grids poses further risks to global grid stability

- Dec. 2015, Paris Agreement
- Dec. 2019, European Union's Green Deal (climate neutrality by 2050)
- Nov. 2020, European Commission Offshore Renewable Energy Strategy (300 GW of offshore wind complemented by 40 GW of other offshore energy technology by 2050)

North Sea Wind Power Hub Programme

North Sea Wind Power Hub consortium
https://northseawindpowerhub.eu/

EUROBAR connecting europe offshore

Eurobar consortium
https://eurobar.org/

IJmuiden Ver Wind Farm Zone in the Netherlands

Multi-vendor, multi-technology PED systems → **Cross-system control coordination and interaction** → **Global system stability**

Introduction

Cross-system control coordination and interaction between PEDs

- Already well testified in the world
- Possible on both AC and DC grids
- Multiple root causes (e.g., control loops, nonlinear functions, harmonic and resonance)
- Adverse consequences (e.g., unexpected oscillatory behavior or dynamics, abnormal protection actions and tripping, power outage, etc.)
- Difficult to detect and mitigate

Multi-Infeed and Interaction Study Interaction between : at least two main power electronic devices (HVDC, FACTS, Renewables, etc.)					
Control loop interaction		Interaction due to non-linear functions		Harmonic and Resonance interaction	
Near steady-state (slow control)	Dynamic (fast controls)	AC fault performance	Transient stress and other non-linear interaction	Sub-synchronous resonance	Harmonic emission and resonance
• AC filter hunting • Voltage control conflicts • P/V stability	• Power oscillation • Control loop interaction • Sub-synchronous control interaction • Voltage stability	• Commutation failure • Voltage distortion • Phase imbalance • Fault recovery • Protection performance	• Load rejection • Voltage phase shift • Network switching • Transformer saturation • Insulation coordination	• Sub-synchronous torsional interaction	• Resonance effects • Harmonic emission • Harmonic instability • Core saturation instability
• Static analysis • RMS time domain	• RMS time domain • EMT time domain • Small-signal analysis	• RMS time domain • EMT time domain	• EMT time domain	• EMT time domain	• Harmonic analysis • EMT time domain • Small-signal analysis

Source: "Guide for electromagnetic transient studies involving VSC converters," Cigré technical brochure, ref. 832, WG B4.70, 2021.

***Previous and ongoing efforts investigating control interaction and improving multi-vendor interoperability**

- Best Path DEMO#2 project (EU's 7th Framework Programme for Research, Technological Development and Demonstration)
- CIGRÉ WG B4.70
- CIGRÉ WG B4.81
- …

EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

February 8, 2022 - Webinar How to de-risk large-scale multi-vendor HVDC systems, lessons from the North Sea Wind Power Hub project

EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

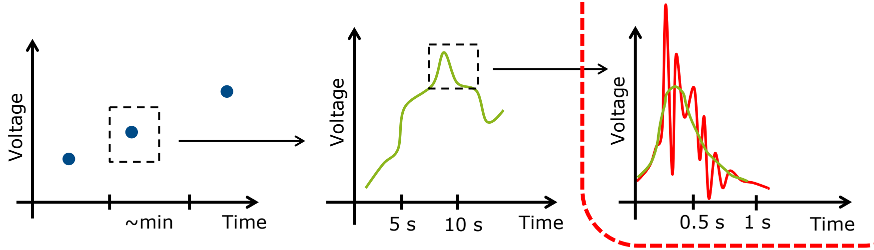
EMT-type simulation

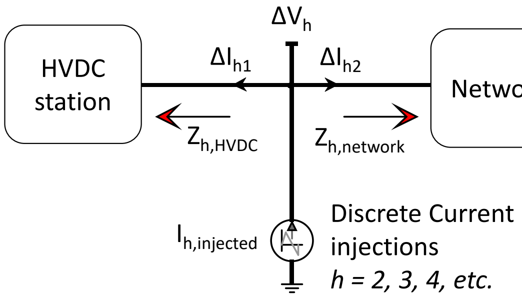
- More accurate circuit component modelling than LF or RMS
- Detailed transient dynamic waveform representation
- Applicable to analyses over a wide range of frequencies
- Appealing alternative for small-signal analysis

Load Flow
- Voltage Stability
- Load flow studies
- 50Hz models

RMS
- Transient stability
- Electromechanical studies
- 50 Hz models

EMT
- Electromagnetic behavior
- Instantaneous voltages and currents
- Dynamic studies
- ~0 Hz to kHz models





$$i_{h\_injection} = \Delta I_{h1} + \Delta I_{h2}$$

$$Z_{h\_hvdc} = \frac{\Delta V_h}{\Delta I_{h2}}$$

Time Domain + $I_{h\_injected}$ → **Measure ΔV_h & ΔI_h** → **Calculation $Z_h = \Delta V_h / \Delta I_h$** → **Frequency Domain Studies**

Drawback: longer simulation time

EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

- **Two types of EMT tools available for multi-vendor interoperability assessment**
  - ➢ Offline EMT simulation (without real-time clock constraints)
  - ➢ Real-time EMT simulation (solution of system equations synchronized with real-time clock)
- **Offline PED EMT models for interoperability assessment**

Generic models

- Models based on standards/pre-standards
- Open-access models
- Models from software library
- In-house specification-based models
- Vendor models from other projects

Vendor black-boxed models

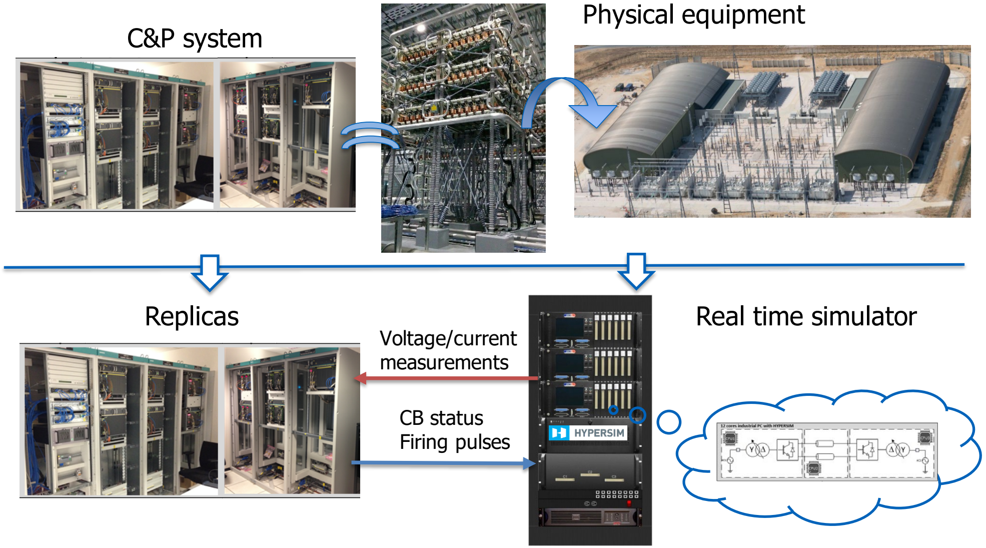
- Complete black-boxed models
- Customized black-boxed models

- **Real-time simulation with Hardware-in-the-loop (HIL) setup**
  - ➢ A complementary solution to offline EMT simulations
  - ➢ Able to connect physical external devices (e.g., C&P replicas) to perform HIL or Power Hardware-in-the-loop (PHIL) simulations

EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

C&P replicas

- "Almost" exact copy of the actual C&P system installed on site
- Simplifications and reductions due to the absence of interface with physical equipment (valves, cooling system, communication system, etc.)
- Different types of replicas are available catering to clients' requirements and needs
- Can be categorized into **study replica** and **maintenance replica**



EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

Comparison between offline and real-time EMT simulations for multi-vendor interoperability assessment

	Offline EMT simulations	HIL setup with C&P replicas
Representation of actual on-site C&P system	Less accurate (code extracted with simplifications, approximations, and assumptions)	Highly accurate (almost exact copies of on-site installation)
Representation of power circuit components	Accuracy can be easily adapted to the study requirements	Accuracy is highly constrained by real-time simulation requirements
Model accessibility and flexibility	Less accessible internal structure, restrictive flexibility in system studies.	More accessible internal structure, associated tools facilitating system studies.
Following on-site system updates	Requires more involved procedures, dedicated resources and special care are necessary to avoid uncertainty and human errors	Easy to track and implement

EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

Comparison between offline and real-time EMT simulations for multi-vendor interoperability assessment (cont'd)

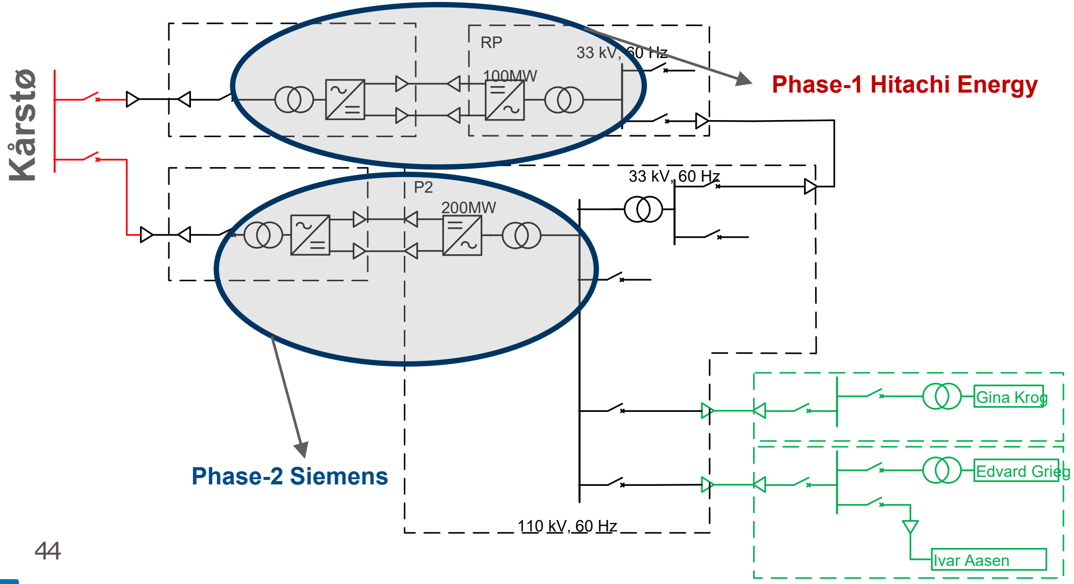
	Offline EMT simulations	HIL setup with C&P replicas
Regarding multi-vendor EMT models	Difficulty in resolving issues regarding vendor-specific simulation requirements	Easy to resolve issues regarding vendor-specific simulation requirements
Operational cost	Less costly	Costly investment in infrastructure, hardware and human resources
Studies of system operation involving operator interventions	Not feasible	Feasible
Studies involving slow-varying dynamics	Possible, but not practical	Feasible
Automatic run of large numbers of sensitivity studies in parallel	Feasible	Feasible but requires C&P software modification

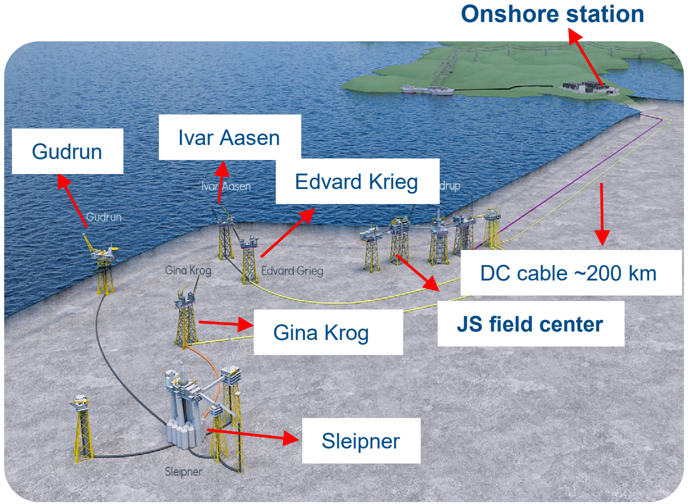
EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

- **Currently available solution for multi-vendor interoperability assessment**

Offline EMT simulation + **Real-time EMT simulation using HIL setup**

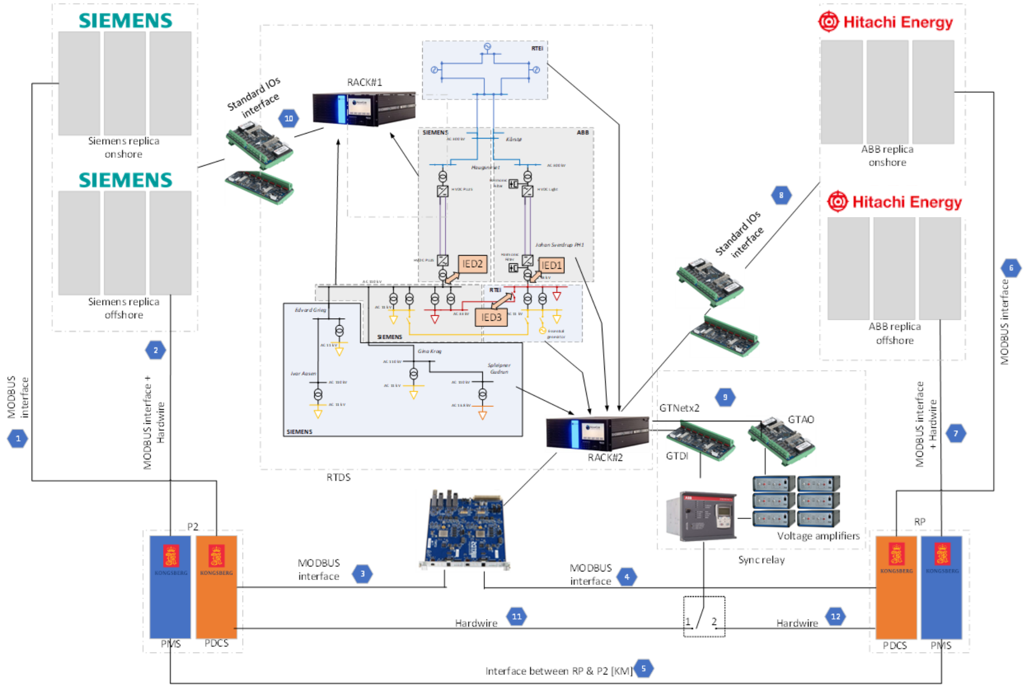
- **An example is the world's first multi-vendor HVDC links supplying power to a large O&G grid**



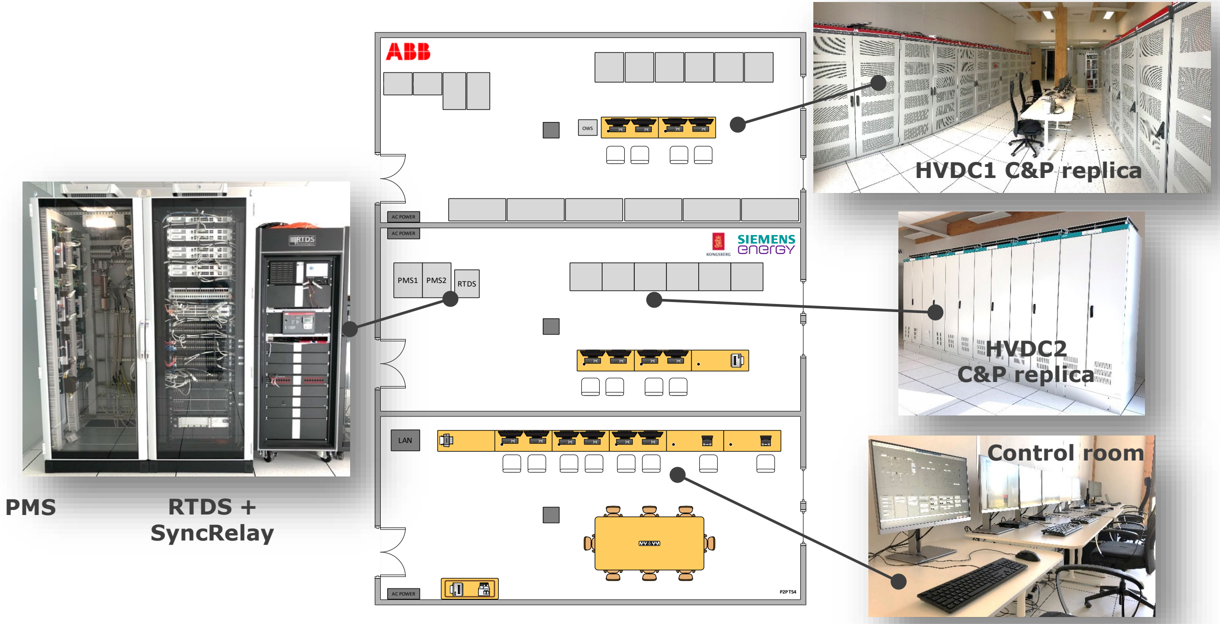


EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

- Secure power supply for JS and neighboring platforms under all operating conditions is paramount.
- Each system has been developed independently with no information exchange due to IP concerns.
- A global controller (PMS), with slow dynamics and requiring operator intervention, has been implemented (not available in EMT models).
- Offline models provided by vendors do not run with the same Δt, not possible to accommodate multi-rate simulation without possible accuracy degradation.



EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT



- C&P replicas are housed separately with secure access.
- Remote access to C&P software has been established for each vendor.
- An iterative procedure has been setup for both offline and RT studies.
- Software changes on commissioned systems strictly limited.

- **Offline EMT simulations to detect any potential interoperability issues in parallel operation.**
- **Selected sets of RTS tests with HIL and C&P replicas for further functional testing prior to HVDC2 commissioning.**

EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT

- Currently, the combination of offline and RT simulations offers an adequate solution to interoperability assessment of multi-vendor converter-dominated systems.
- However, in the context of developing and integrating large-scale offshore grids,
    - ➢ non-negligible procurement cost of C&P replicas
    - ➢ stringent infrastructural requirements for HIL lab facilities
    - ➢ difficulty in accommodating resource management issues
    - ➢ substantial resources dedicated to study result benchmarking and validation

→ HIL setup is likely to reach its limits for future large offshore DC grid development.

POSSIBLE DIRECTIONS TO SECURE THE DEVELOPMENT OF LARGE-SCALE OFFSHORE GRIDS

CHALLENGES FOR THE DEVELOPMENT OF FUTURE LARGE-SCALE OFFSHORE GRIDS

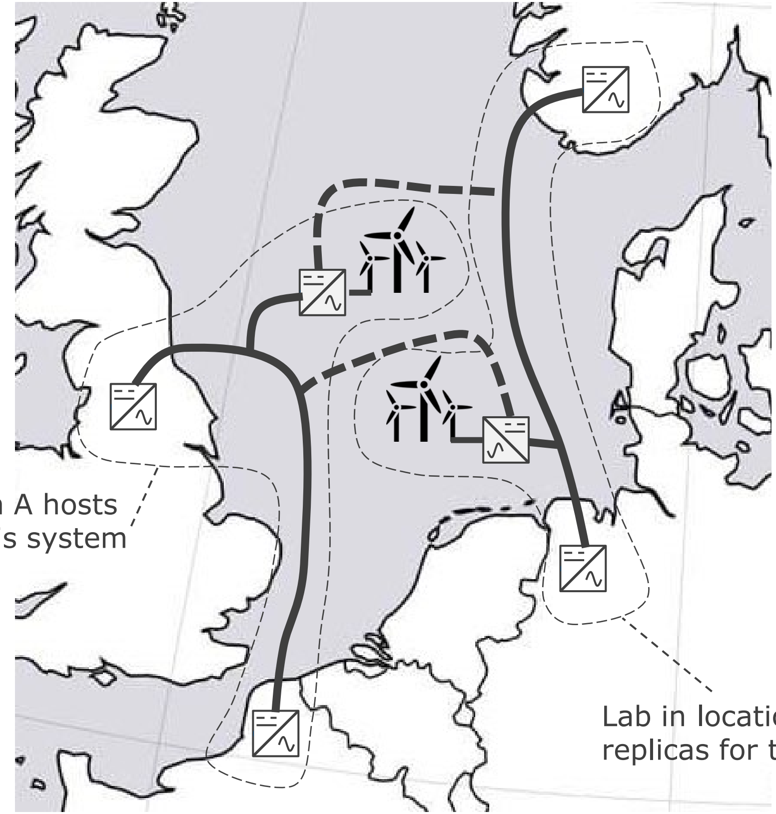
Presently EMT offline simulation cannot be the only de-risking solution

Incomplete C&P functions and limited hardware environment representation

Lack of proper long-term model maintenance

Vendor-specific offline EMT models not yet designed for interoperability studies

EMT-AIDED MULTI-VENDOR INTEROPERABILITY ASSESSMENT



Lab in location A hosts replicas for this system

Lab in location B hosts replicas for this system

Step1: HVDC link1 construction

Step2: HVDC link2 construction

Step3: Tap connection of OWF on HVDC link1

---- System studies with replicas of all converters connected to HVDC link1 in lab A ------

Step4: Tap connection of OWF on HVDC link2

---- System studies with replicas of all converters connected to HVDC link2 in lab B ------

What are the solutions to develop connections between the 2 systems?

POSSIBLE SOLUTIONS – IMPROVEMENT IN PED MODELS

Improvements in specifications

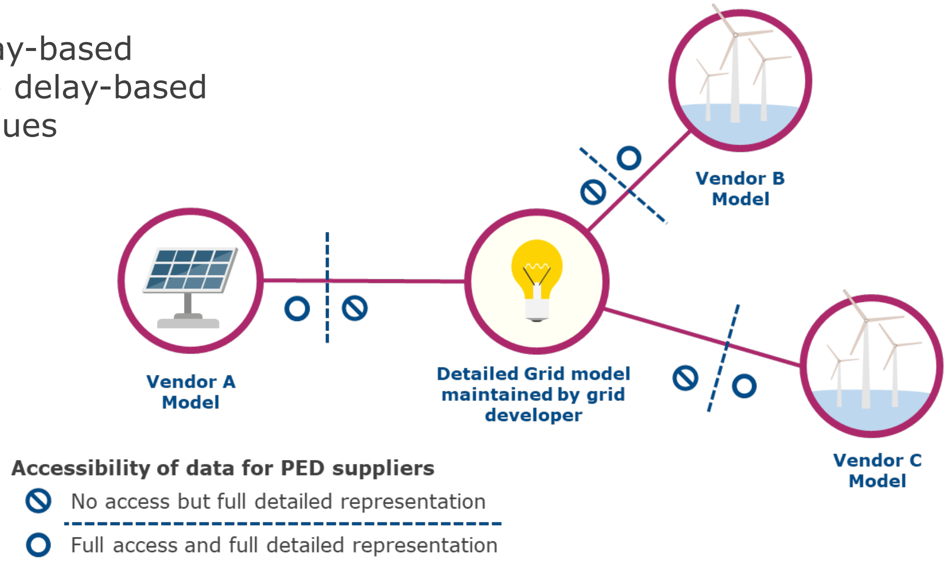
- Many on-going initiatives (ENTSO-E, CIGRE/IEEE, AEMO,…)
- To cover different topics:
  - accuracy (i.e., the minimum level of details);
  - interoperability between models provided by different vendors;
  - maintenance and update;
  - simulation speed

Improvements in models

- Better representation of C&P hardware in the model
- Improved solutions to facilitate maintenance of models
- The Digital Twin concept can support improvements in models

POSSIBLE SOLUTIONS – IMPROVEMENT IN OFFLINE SIMULATION TOOLS

- **Improve calculation speed and accuracy with software adaptation**
  - Parallel computing time delay-based
  - Parallel computing non-time delay-based
  - Improved numerical techniques
- **Improve calculation speed and accessibility of data with adapted hardware**
  - Continuous increase in the single-threaded CPU performance
  - Cloud-based computing techniques applied on large grid simulators with access control



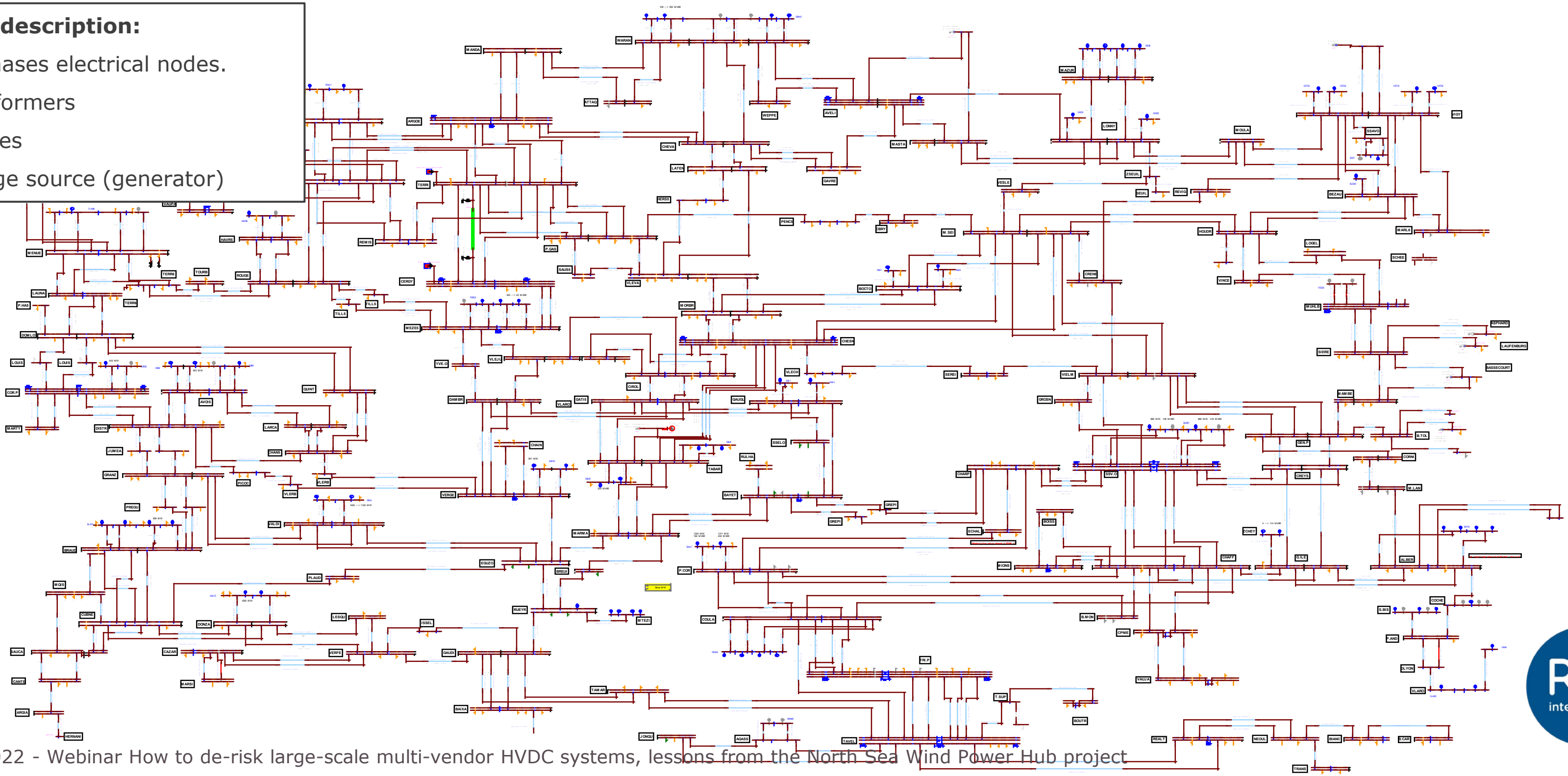
STUDIES FOR CONVERTER-DOMINATED LARGE-SCALE SYSTEMS

Offline simulation of large-scale systems is feasible !

400kV French grid

EMTP file description:

- 1400 3-phases electrical nodes.
- 250 transformers
- 850 CP lines
- 150 Voltage source (generator)



POSSIBLE SOLUTIONS – TOWARDS A QUALIFICATION PROCESS

Context

- Development of large-scale converter-based grids presently required strong coordination with all stakeholders at different stages of the project
- Studies coordinated with all stakeholders are usually demanding in time and resources
- A qualification process to test interoperability could facilitate this development

In case of system expansion, the qualification process should be applied on:

- The existing system: is it prepared to be interfaced with a new sub-system?
- The new system: is it designed to be integrated into an existing system?
- The global system: does the entire system work properly ?

The qualification process is composed of 2 types of activities:

- **Step1 - Testing of Multi vendor readiness requirements:**
  - List of multi vendor readiness requirements
  - Applied on a single subsystem
  - Check that the subsystem is ready to be integrated into a multi vendor system
- **Step2 - Integration tests for multi vendor systems:**
  - List of integration tests
  - Applied on a global system composed of subsystems provided by different vendors
  - Check that performances are as expected, if abnormal interactions are detected then solutions can be implemented

CONCLUSION

Insight from RTEi on development of large-scale converter-based systems

- Use of EMT simulation
- Combination of EMT offline and EMT real-time simulation is mandatory
- A real-time lab facility can bring crucial value to de-risk this type of project

New offshore wind developments bring new challenges

- HiL simulation with physical replicas will be sufficient to de-risk very large project
- Offline EMT models and simulations tools are not fully prepared yet

Different directions to secure future development

- Improved model specifications
- Improved model performances
- More advanced simulation tools
- Development of qualification processes for multi vendor readiness

Q&A

Markus Vor dem Berge, Director Power Eletronics and Studies at RTE international
Tel : +33622580838Email : markus.vor-dem-berge@rte-international.com
www.rte-international.com