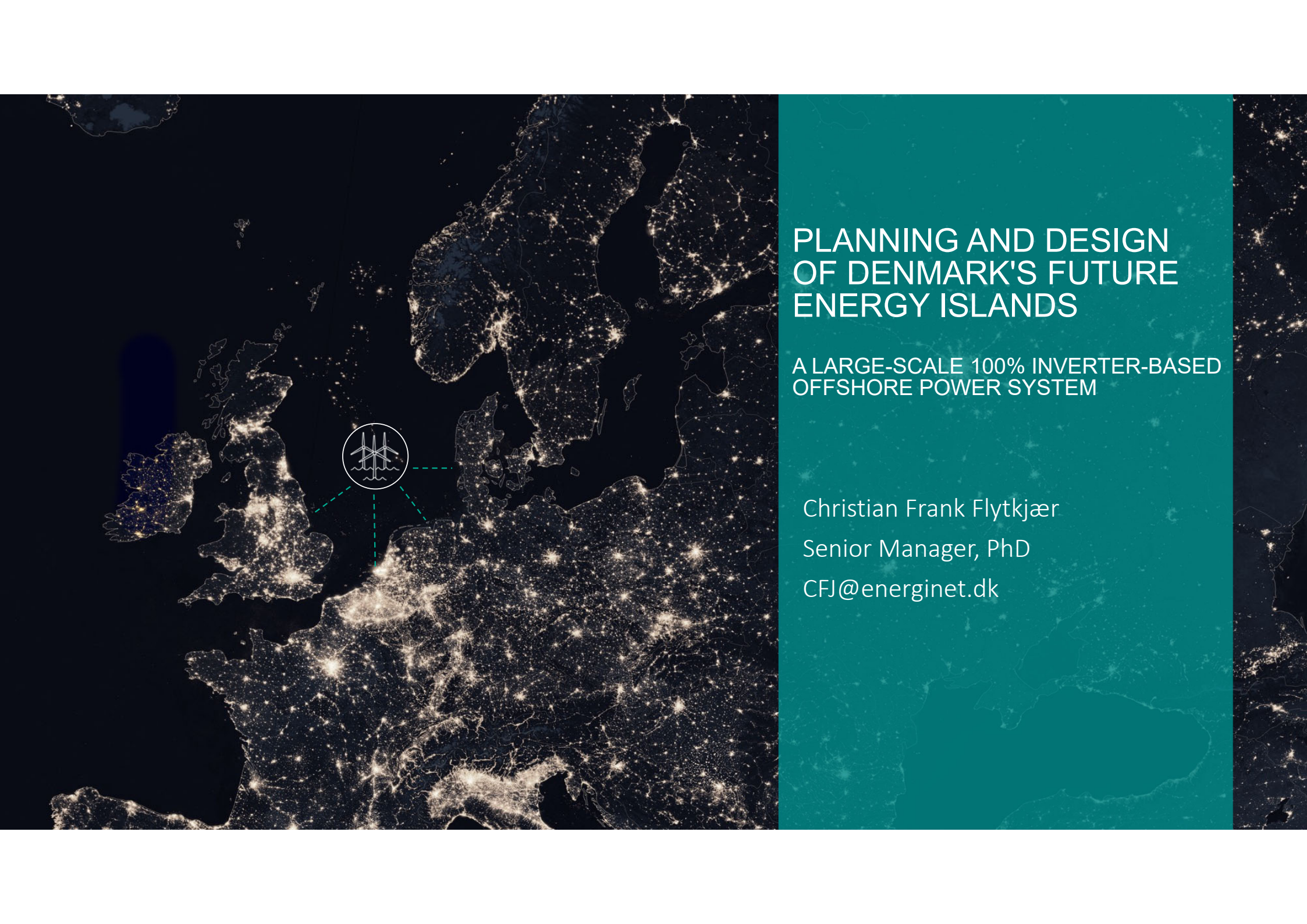




PLANNING AND DESIGN OF DENMARK'S FUTURE ENERGY ISLANDS

A LARGE-SCALE 100% INVERTER-BASED
OFFSHORE POWER SYSTEM

Christian Frank Flytkjær
Senior Manager, PhD
CFJ@energinet.dk

CONTENTS

A topographical map of Europe is shown in the background. The landmasses are colored in shades of green and brown to represent different elevations. The surrounding oceans are a deep teal color. Two yellow circular markers with white outlines are placed on the map: one in the North Atlantic between the British Isles and Scandinavia, and another in the Baltic Sea between the Scandinavian Peninsula and Central Europe.

BACKGROUND

ELECTRICAL SYSTEM DESIGN OF ENERGY HUBS

TECHNICAL CHALLENGES TO OVERCOME

ANALYTICAL TOOLS AND MODELS



DANISH GREEN TRANSITION

STATUS 2020:

64 % green national electricity production

50% wind and solar electricity production

37 % green energy system

2030 TARGET:

100% green electricity production

70% emission reduction

2050 TARGET:

Climate-neutral

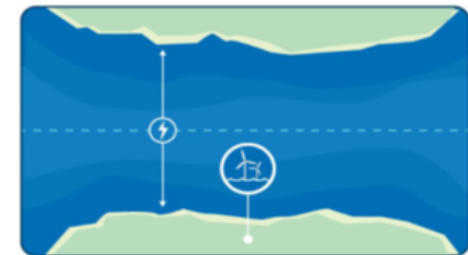
EUROPEAN GREEN DEAL

300+ GW offshore wind by 2050

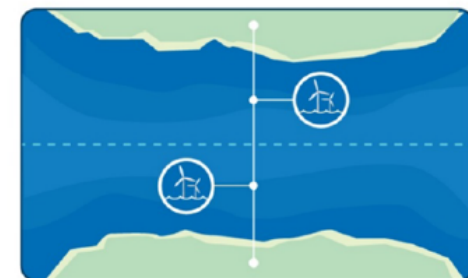
- The EU aims to be climate-neutral by 2050
- *An EU strategy to harness the potential of offshore renewable energy for a climate neutral future*
 - In order to step up offshore renewable energy deployment in a cost-efficient and sustainable way, **more rational grid planning and development of a meshed grid is key**. In this context, the concept of so-called hybrid projects has been given considerable attention over the last years.*



Today



The future



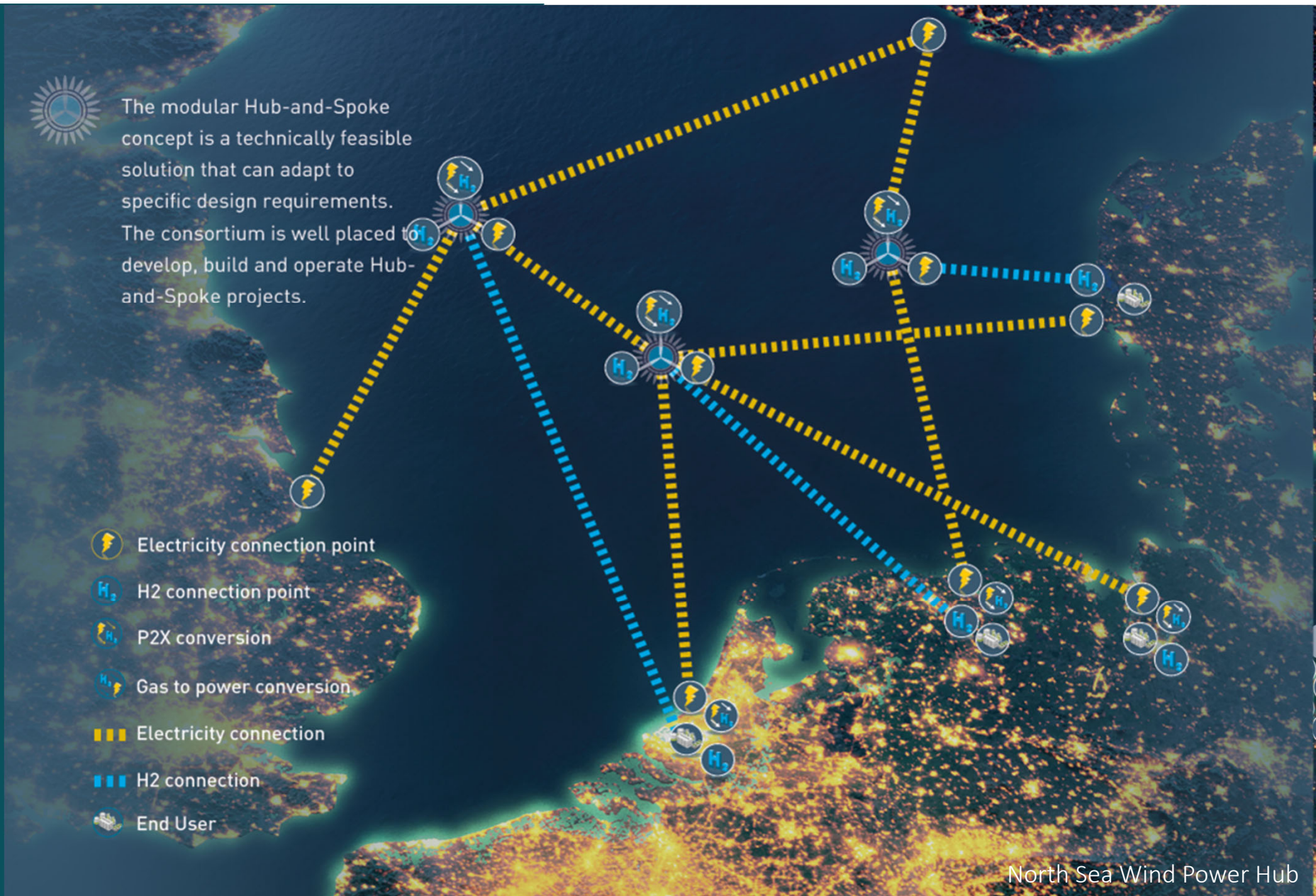
**An EU strategy to harness the potential of offshore renewable energy for a climate neutral future.*

A POSSIBLE VERSION OF THE FUTURE



The modular Hub-and-Spoke concept is a technically feasible solution that can adapt to specific design requirements. The consortium is well placed to develop, build and operate Hub-and-Spoke projects.

-  Electricity connection point
-  H2 connection point
-  P2X conversion
-  Gas to power conversion
-  Electricity connection
-  H2 connection
-  End User



North Sea Wind Power Hub

WORLD'S FIRST ARTIFICIAL ENERGY ISLAND

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

 NEW OFFSHORE WIND FARMS

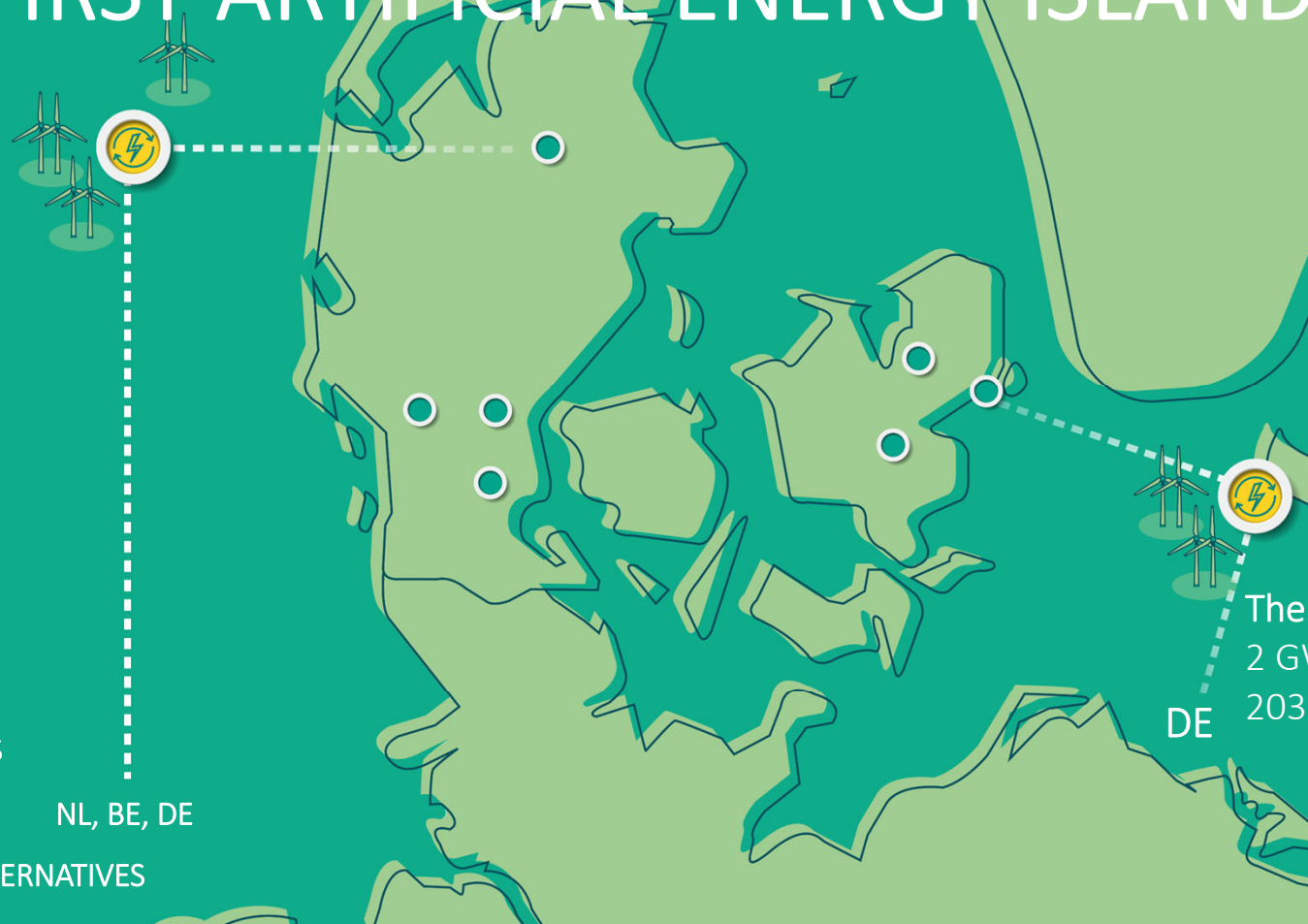
 ENERGY ISLAND

 ONSHORE CONNECTIONS, ALTERNATIVES

NL, BE, DE

The Baltic Sea:
2 GW offshore wind by
2030.

DE

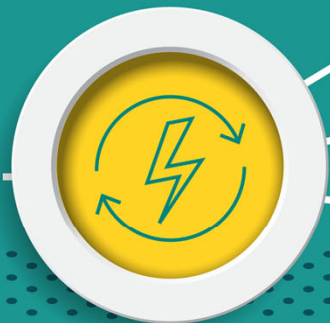
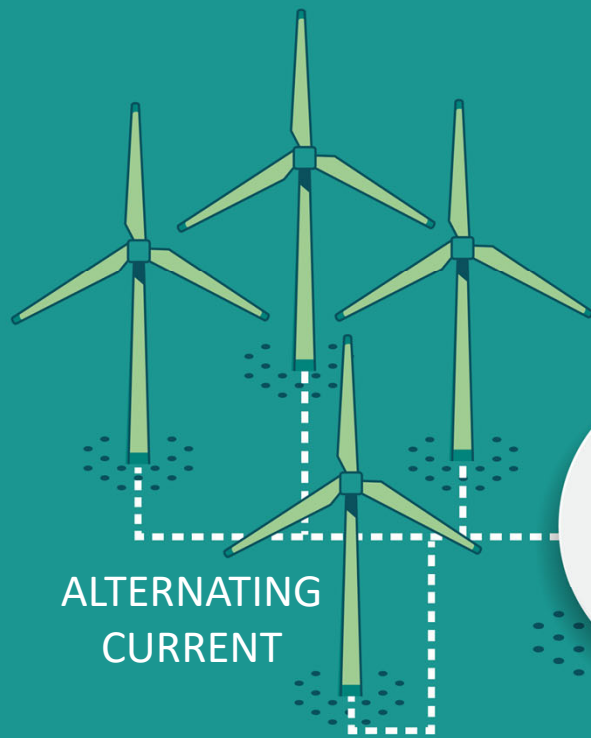


ENERGY HUB CONCEPT

10 GW

HUB

Landing facilities



DIRECT CURRENT

DIRECT CURRENT

HYDROGEN



ALTERNATING
CURRENT



HYDROGEN



GREEN FUELS

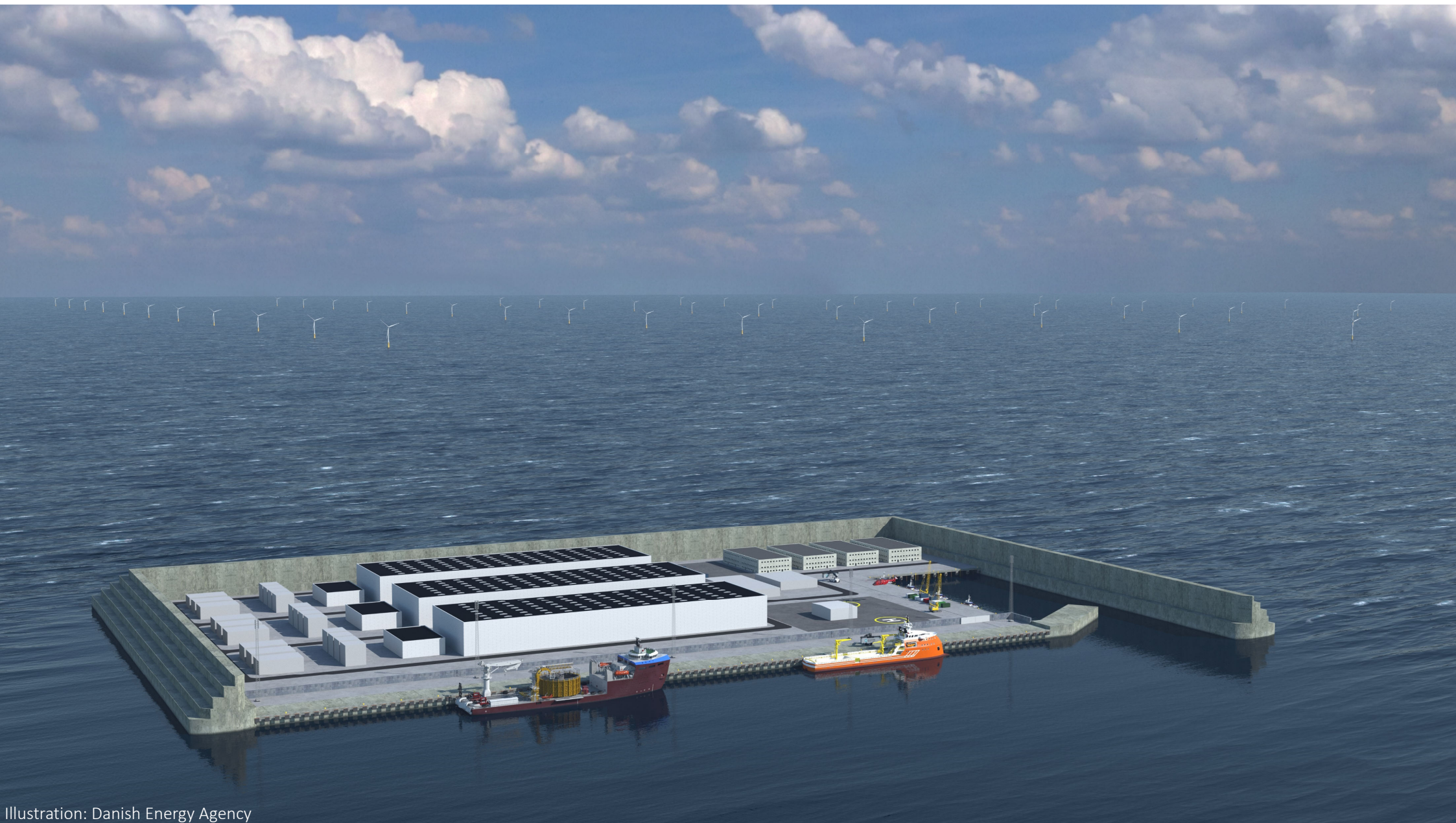
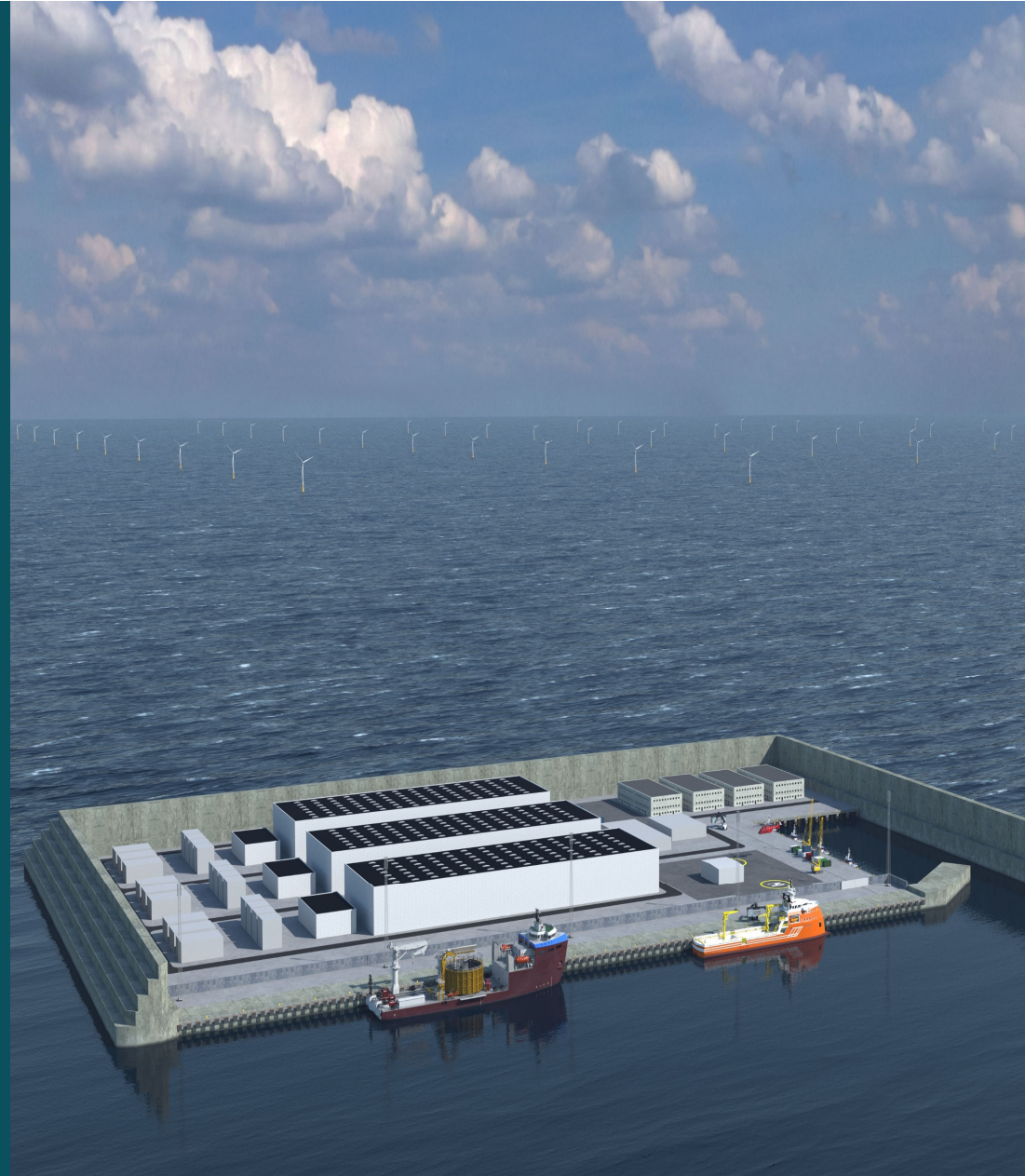
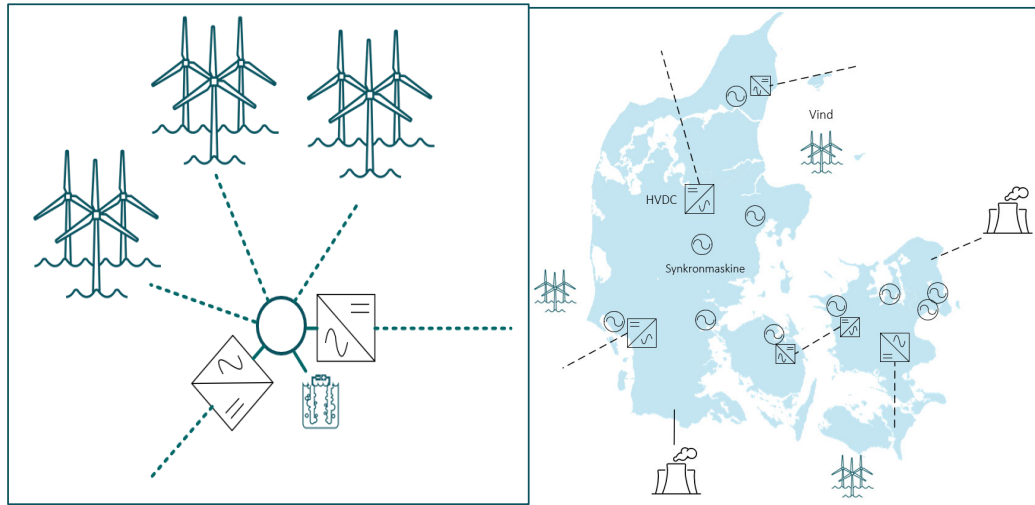


Illustration: Danish Energy Agency

ELECTRICAL SYSTEM DESIGN OF ENERGY HUBS



Electrical system design of energy hubs



- The energy hub is an extreme version of the future inverter-based power system.

Task given:

Plan, design and operate:

- offshore power system
- landing facilities
- interconnectors

Task added:

- *Measure every electron out there*
- Quantify and qualify them
- Share data to the highest extend possible

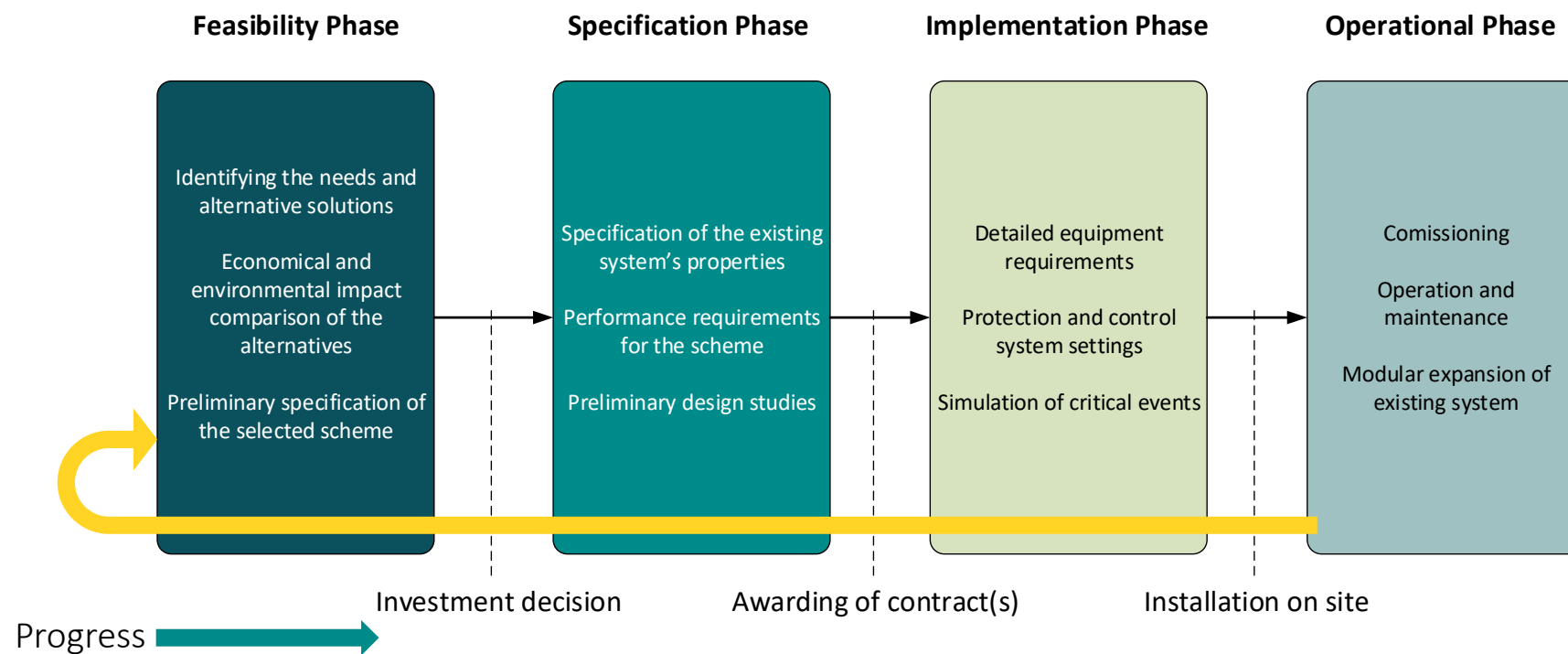


PROJECT PHASES

Phases are typically mostly based on experience

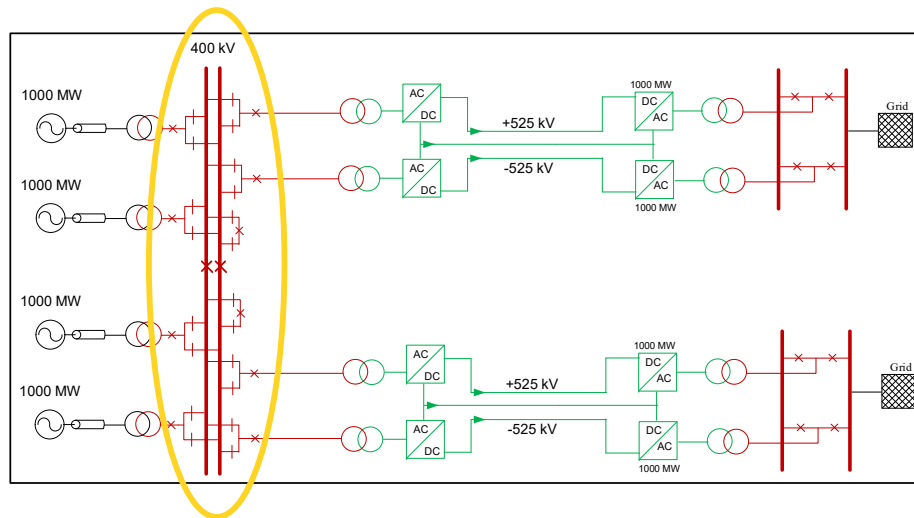
Two main differences

- Little experience for each phase to build on
- The linear process becomes cyclic

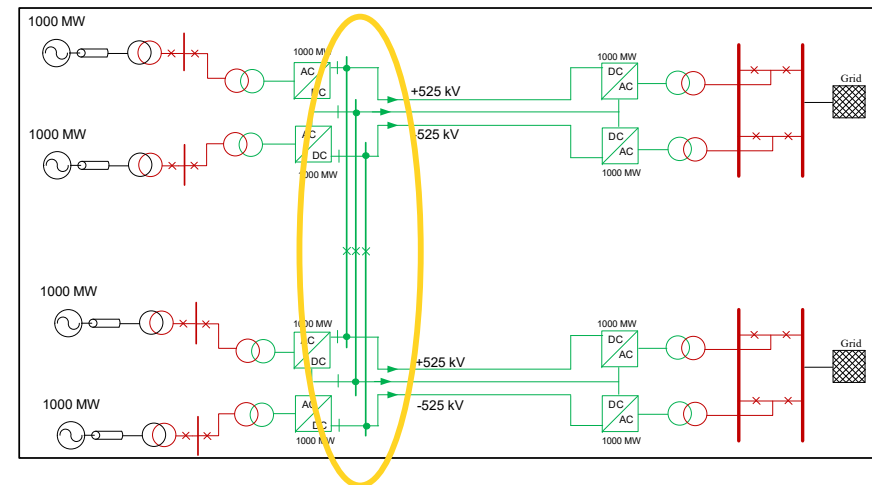


TOPOLOGY CANDIDATES

The largest decision in the feasibility phase



AC-hub



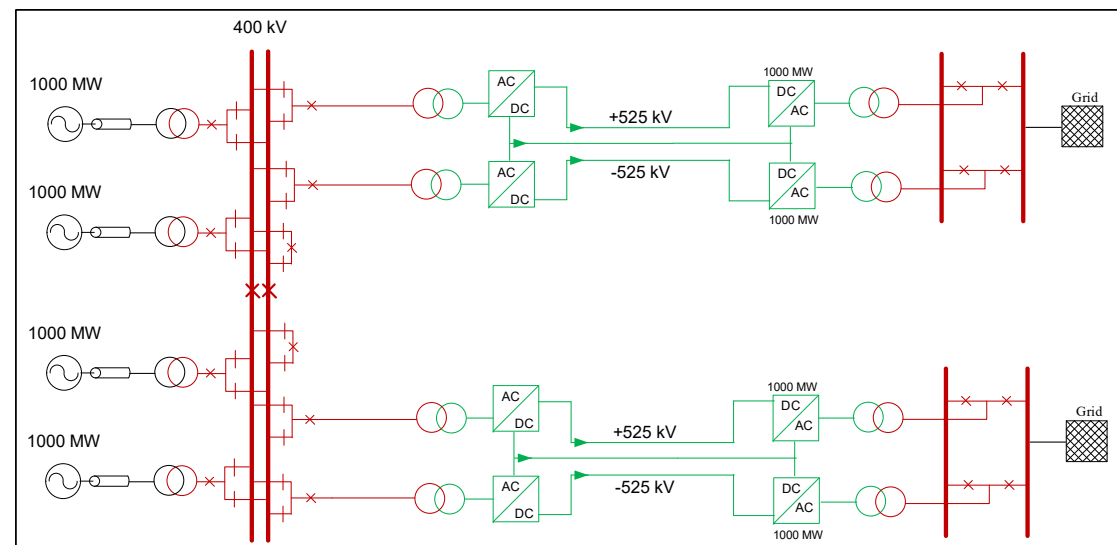
DC-hub

TOPOLOGY CANDIDATES

Technology features of AC-hub

Technology features:

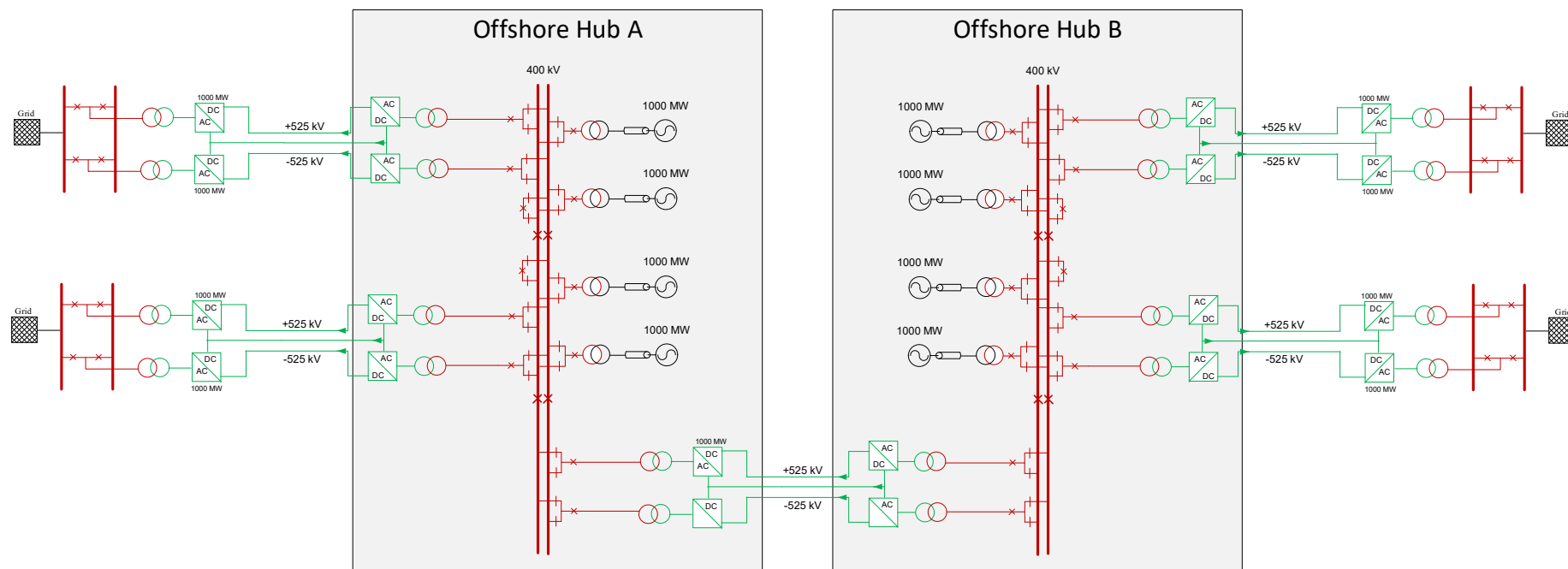
- Point-to-point HVDC solution
- Using a bipole HVDC system, loss of largest unit equals the rating of one pole
- Connection of load, e.g. PtX plants, directly to AC busbar.



TOPOLOGY CANDIDATES

Connection to other hubs or countries

- Connecting other hubs requires a full HVDC link
- De-coupled hubs by control possible

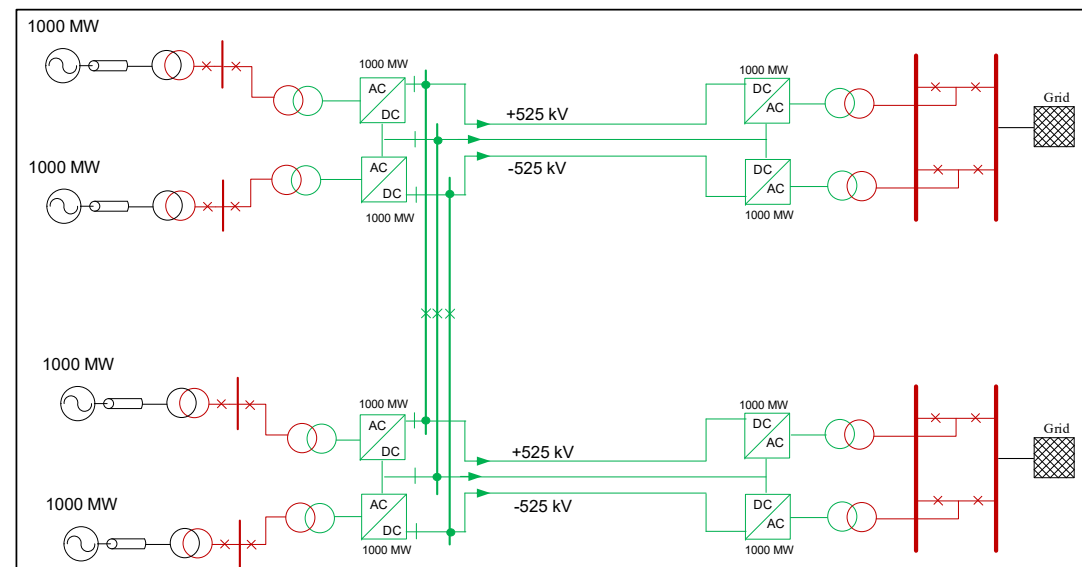


TOPOLOGY CANDIDATES

Technology features of DC-hub

Technology features:

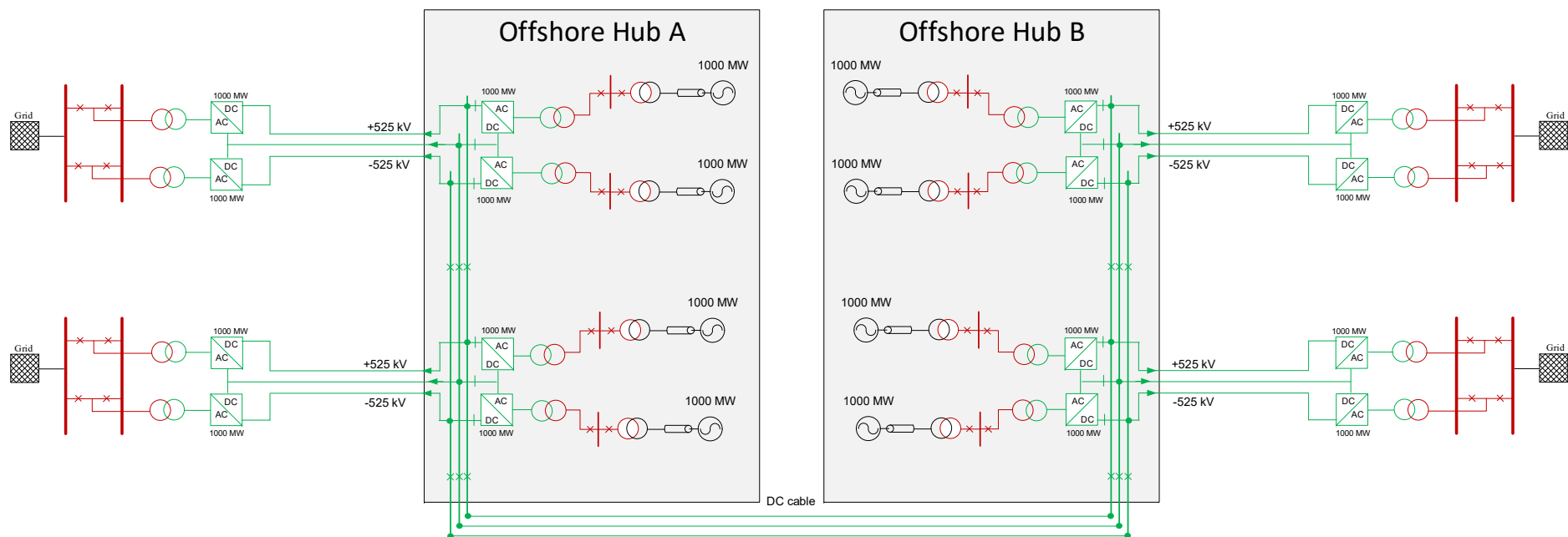
- Multi-terminal HVDC technology
- Using a bipole HVDC system, loss of largest unit equals the rating of one pole
- Connection of load, e.g. PtX plants, directly to AC busbar of one HVDC
- For cost-efficient expansion, a multi-vendor framework is required.



TOPOLOGY CANDIDATES

Connection to other hubs or countries

- Connecting other hubs requires a DC connection only
- Connecting hubs affects all DC-system controllers significantly

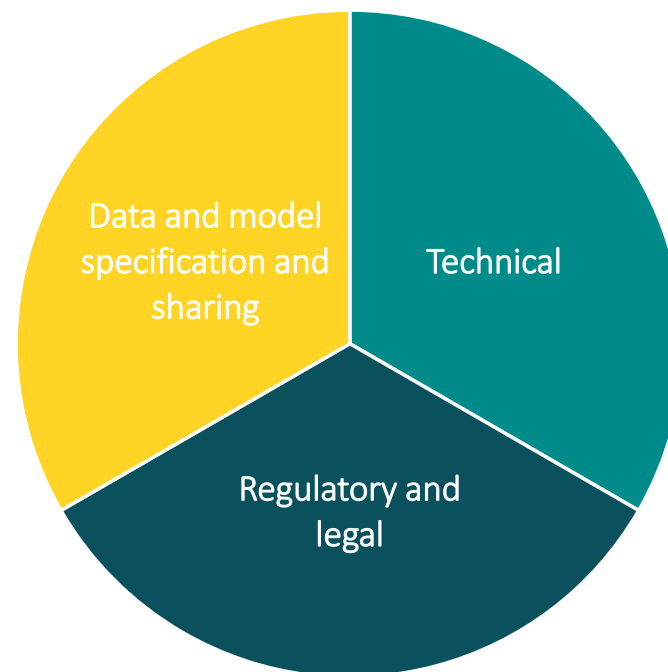


MODULARITY BY DESIGN

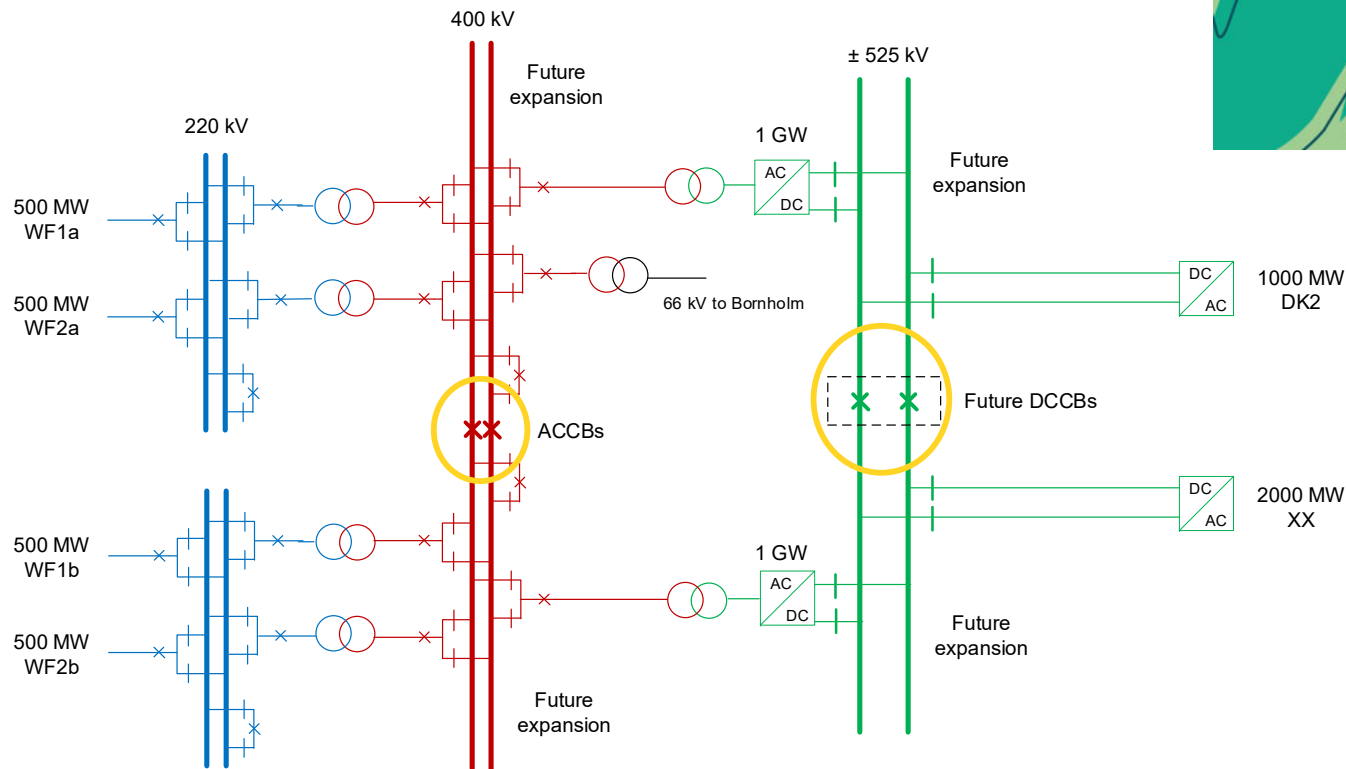
“Energy islands should be expandable”

- Multi-vendor interoperability is more than a technical issue - much more
- Relevant regardless of choice of topology

Modularity and interoperability



MIX OF TOPOLOGIES AS A LEARNING EXPERIENCE?

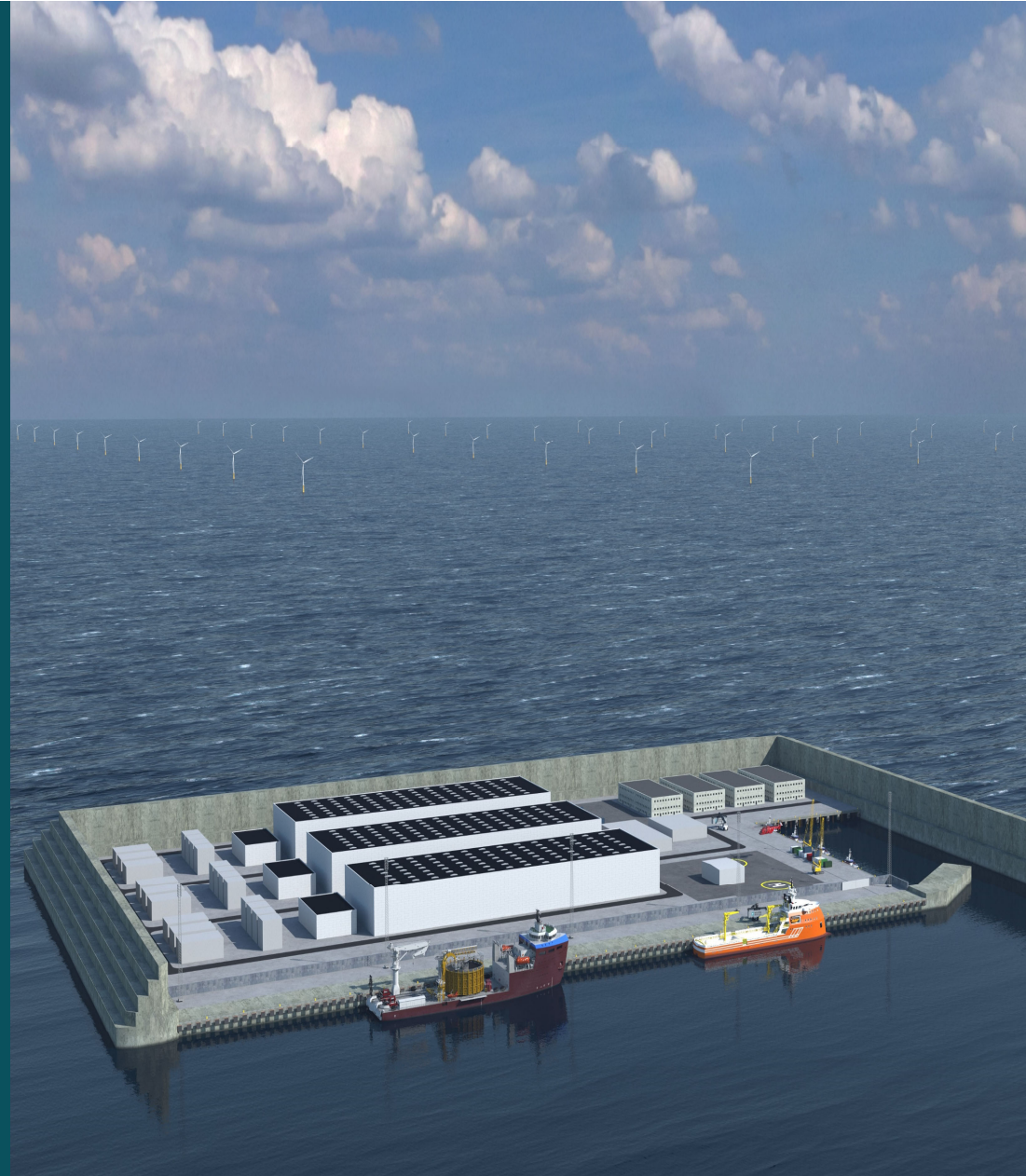


An investment in the future?

- Both AC- and DC-connected busbars could be established?

TECHNICAL CHALLENGES

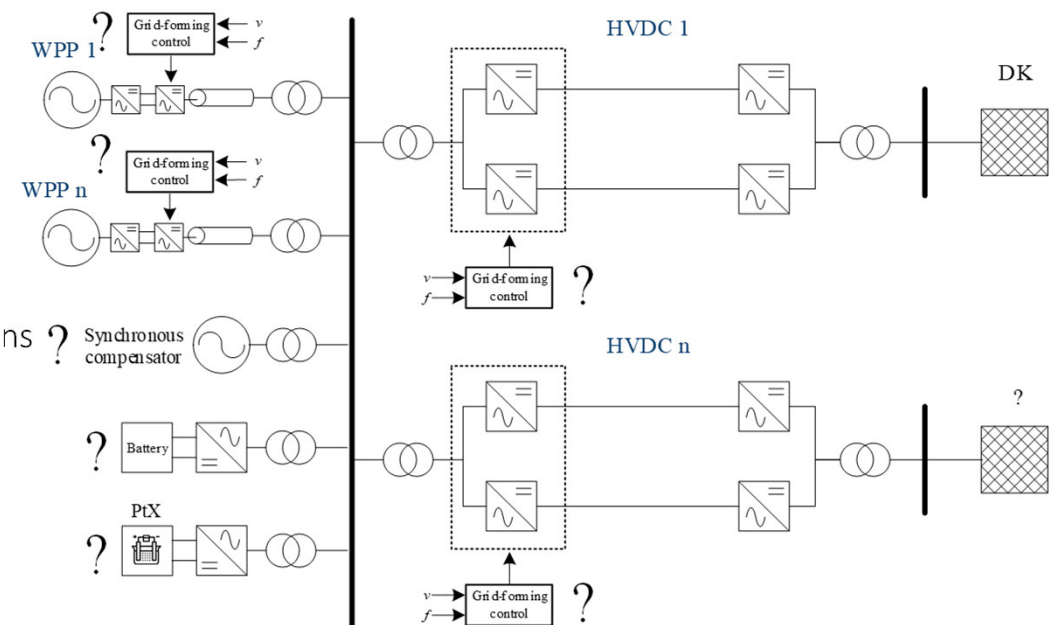
To overcome



HVDC-BASED WIND POWER LANDING

AC hub – specifying a new offshore power system

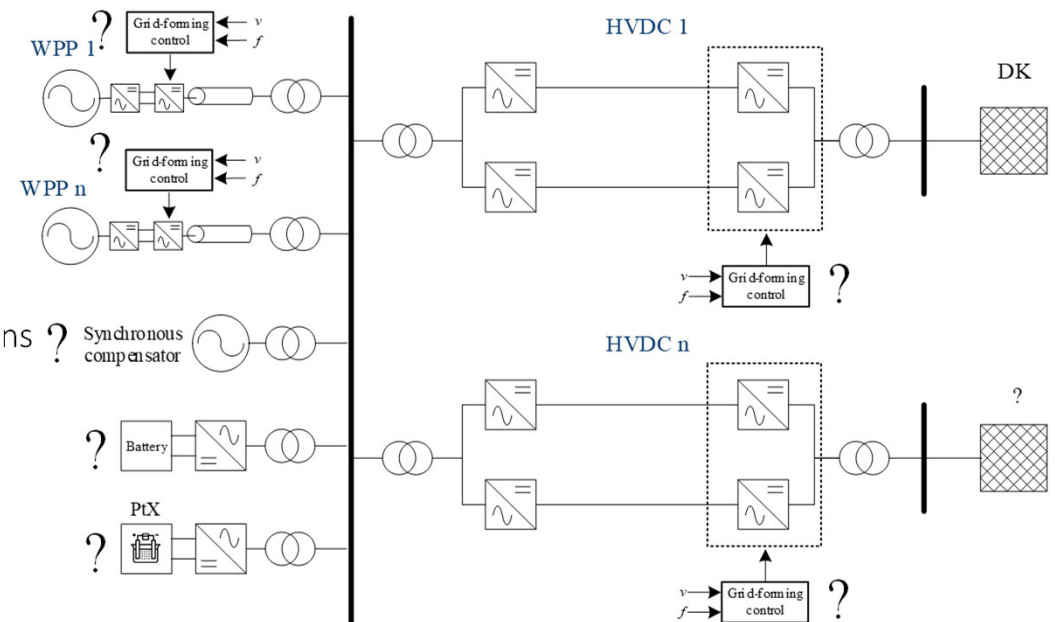
- Normal operation
 - Normal operation voltage and frequency bands
 - Voltage and frequency control
- Disturbances
 - The system's dynamics during events
 - Tight *coupling* between plants – adverse interactions ?
- Grid-forming functionality
 - Where to “grid-form”, how to specify?
- Influence onshore
 - Offshore fast dynamics propagating onshore
 - Loss of largest unit – effect of adverse interactions?



HVDC-BASED WIND POWER LANDING

AC hub – specifying a new offshore power system

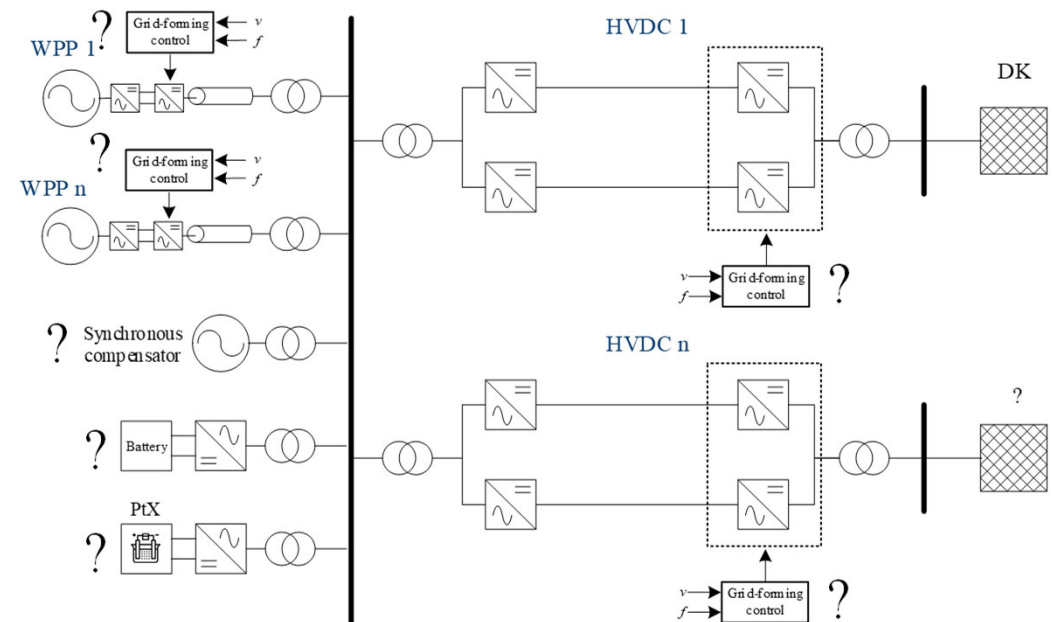
- Normal operation
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HVDC-BASED WIND POWER LANDING

AC hub – specifying a new offshore power system

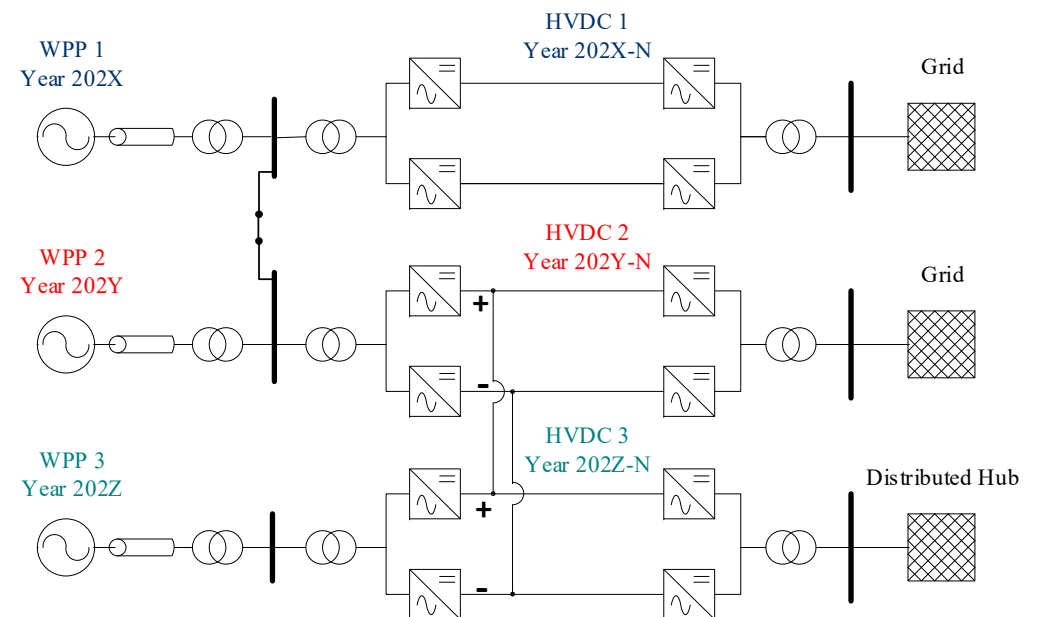
- Adding rotating mass – good idea, bad idea?
- Protection philosophy
- Power quality management
- Hub monitoring and early warning early prevention systems
- ... and probably many more.



HVDC-BASED WIND POWER LANDING

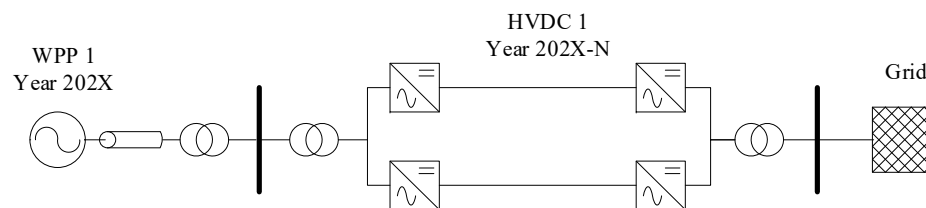
DC hub – specifying not yet proven technology

- Assessment of risk and benefit
- Interoperability of HVDC systems provided by different vendors
 - Technical framework
 - Regulatory framework
- Multi-country HVDC grids
 - DC grid control and operation
 - DC grid codes
- ...



HVDC-BASED WIND POWER LANDING

Expandability

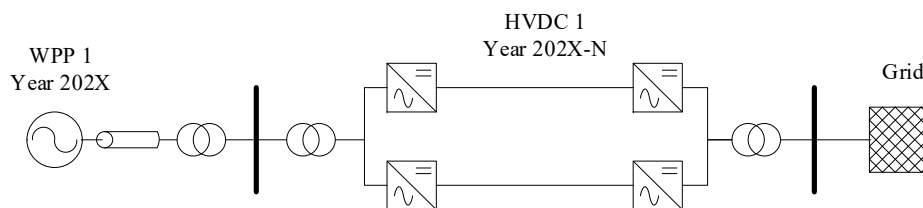


Issues to tackle:

- A very weak offshore AC grid requires closer attention on HVDC and WPP control systems
- A series of problems have been encountered
- Existing solutions are known from Germany, among others

HVDC-BASED WIND POWER

Expandability



Knall auf hoher See

Ökostrom Elektrotechniker rätseln: Die Konverterstation eines Offshore-Windparks schmort durch. Sind alle im Bau befindlichen Anlagen davon betroffen?

Der riesige Kasten steht auf gelben Stelzen, mitten in der Nordsee. Die Luft in seinem Hauptraum ist rein wie in einer Chipfabrik. Es herrscht Überdruck, und das auf einer Plattform rund hundert Kilometer vor Borkum.

Doch am 23. März dieses Jahres, gegen 22 Uhr abends, macht sich beißender Geruch breit. Der Kunststoff von Isolatoren beginnt zu schmoren. Dann knallt es. Jetzt wissen die Ingenieure: Der Traum vom sauberen Strom von hoher See ist für eine ganze Weile ausgetraut.

Zwei Filter der Konverterstation Borwin Alpha sind durchgekokeit, zerstört wohl durch den wilden Fluss von elektrischen Schwingungen, die aus dem Windpark Bard 1 in die Konverterstation strömen.

Dabei waren die Techniker die Tage zuvor noch frohen Mutes gewesen. Endlich hatten sie alle 80 Windräder des Parks zusammenschalten können. Die Dreiflügler drehten sich im kräftigen Wintersturm und produzierten bis zu 400 Megawatt Wechselstrom, der in der Anlage zu Gleichstrom umgewandelt wurde. Zum ersten Mal sollte die Elektrizität mit voller Leistung zu den Haushalten am Festland fließen.

Bard 1 ist der erste jener großen Offshore-Windparks, der mit dem Stromkabel

nächsten Park, der schon im September ans Netz gehen soll? Trianel Windpark Borkum heißt er, gehört dem Stadtwerkunternehmen Trianel, und an guten Tagen ist er von Bard 1 sogar mit bloßem Auge zu sehen. Wird es wieder so eine böse Überraschung geben? „Wir können es nicht vorhersagen“, erklären die Trianel-Techniker.

Für die gesamte Ökostrom-Branche ist das ein Problem. Gerade hatte sie wieder Rückenwind verspürt, nachdem Bundeswirtschaftsminister Sigmar Gabriel (SPD) mit seiner Novelle des Erneuerbare-Energien-Gesetzes (EEG) die Offshore-Windkraft weitgehend verschont hatte.

Die Investoren kommen zurück, die Pläne für Windparkprojekte in Nord- und Ostsee werden wieder ausgerollt. Doch mit jedem Tag, an dem die Techniker auf der Plattform Borwin Alpha im Nebel stochern, wächst die Unruhe bei Banken und Investoren, die Kapital für die Milliardenprojekte zuschießen.

Eigentlich sollte Bard 1 Anfang Juni wieder Strom ans Festland liefern, dann Anfang Juli, dann im August. Jetzt traut man sich bei Tenet schon nicht mehr, ein verbindliches Datum anzugeben. Gleich vier Universitäten hat das Unternehmen in die Spurensuche tief in den Spulen und Schaltkreisen von Borwin Alpha eingeschaltet.

Doch längst beteiligen sich nicht nur Ingenieure an der Reparatur, sondern Anwälte sind auf den Plan getreten. Inzwischen läuft alles auf die Frage hinaus, wer die Schuld an dem Fiasko trägt – und die Kosten.

Ursache für die Misere ist eine Eigenart der deutschen Offshore-Windparks: Sie liegen fast alle so weit von der Küste entfernt, dass der von ihnen erzeugte Strom mit herkömmlicher Technik nicht beim Verbraucher ankommt.

Die Hochspannungsunterwasserkabel funktionieren aber über größere Entfernungen nicht mit der gängigen Wechselstromtechnik. Die Elektrizität muss deshalb mit Gleichstromkabeln an Land transportiert werden.

Das klingt einfach, ist aber auf See ein anspruchsvolles Unterfangen. Die sogenannten Hochspannungs-Gleichstrom-Übertragungsanlagen, im Fachjargon auch kurz HGU-Anlagen genannt, werden derzeit nur von drei Herstellern weltweit angeboten, und nur zwei haben bereits solche Werke für den Offshore-Einsatz tatsächlich gebaut: ABB und Siemens.

ABB war der erste Anbieter von Offshore-HGU-Anlagen überhaupt, und ausgemacht die Exklusivrolle.

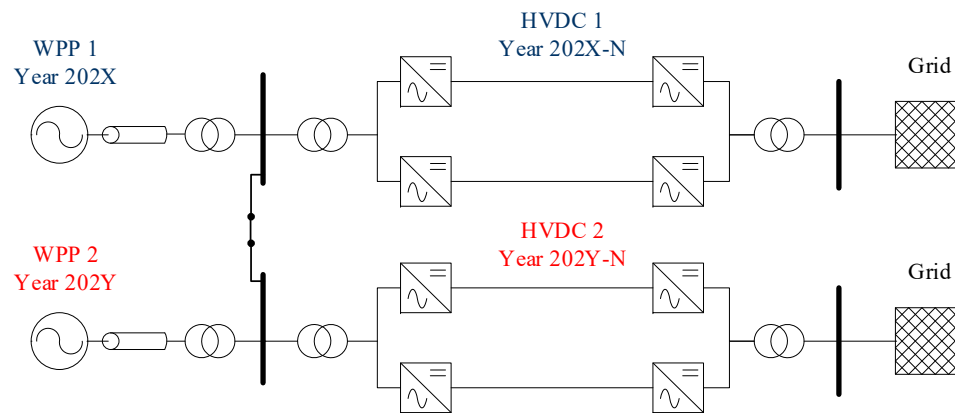


systems

- A series of problems have been encountered
- Existing solutions are known from Germany, among others

HVDC-BASED WIND POWER LANDING

Expandability

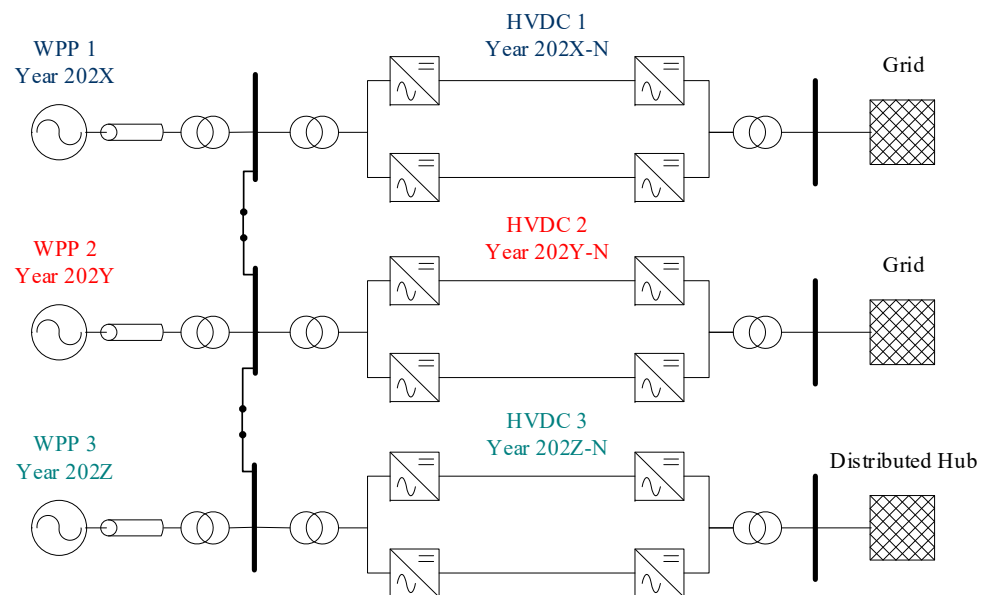


Issues to tackle:

- All existing issues
- Introducing additional equipment in an extreme environment
- Flexible controls and equipment: How should we invest in an uncertain future?

HVDC-BASED WIND POWER LANDING

Expandability

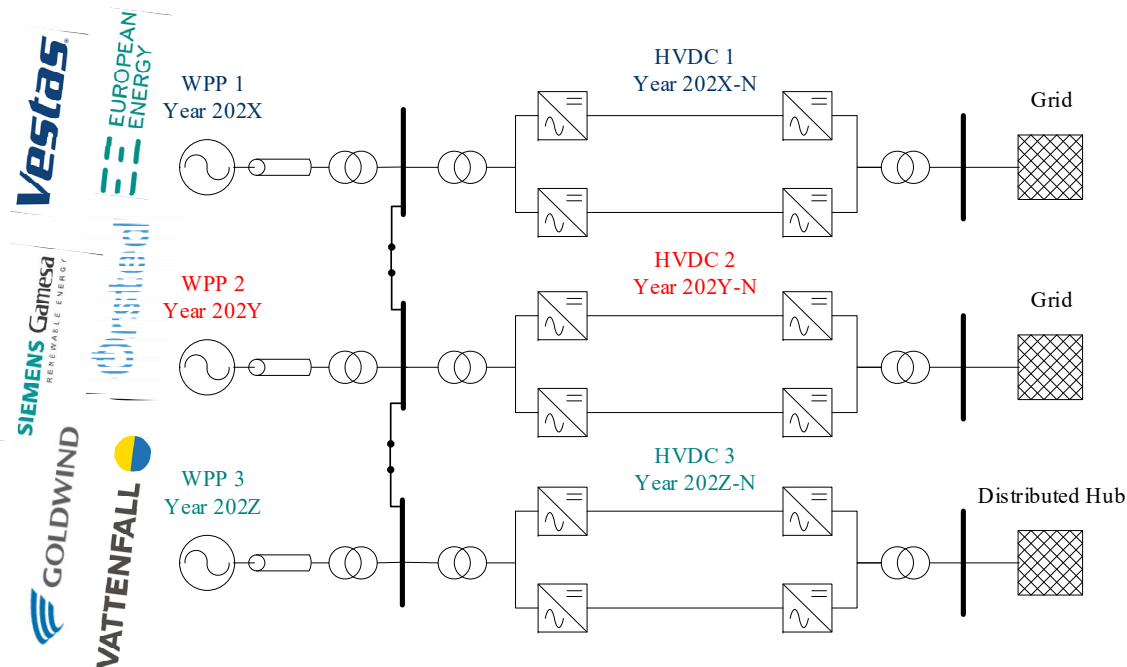


Issues to tackle:

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HVDC-BASED WIND POWER LANDING

Expandability

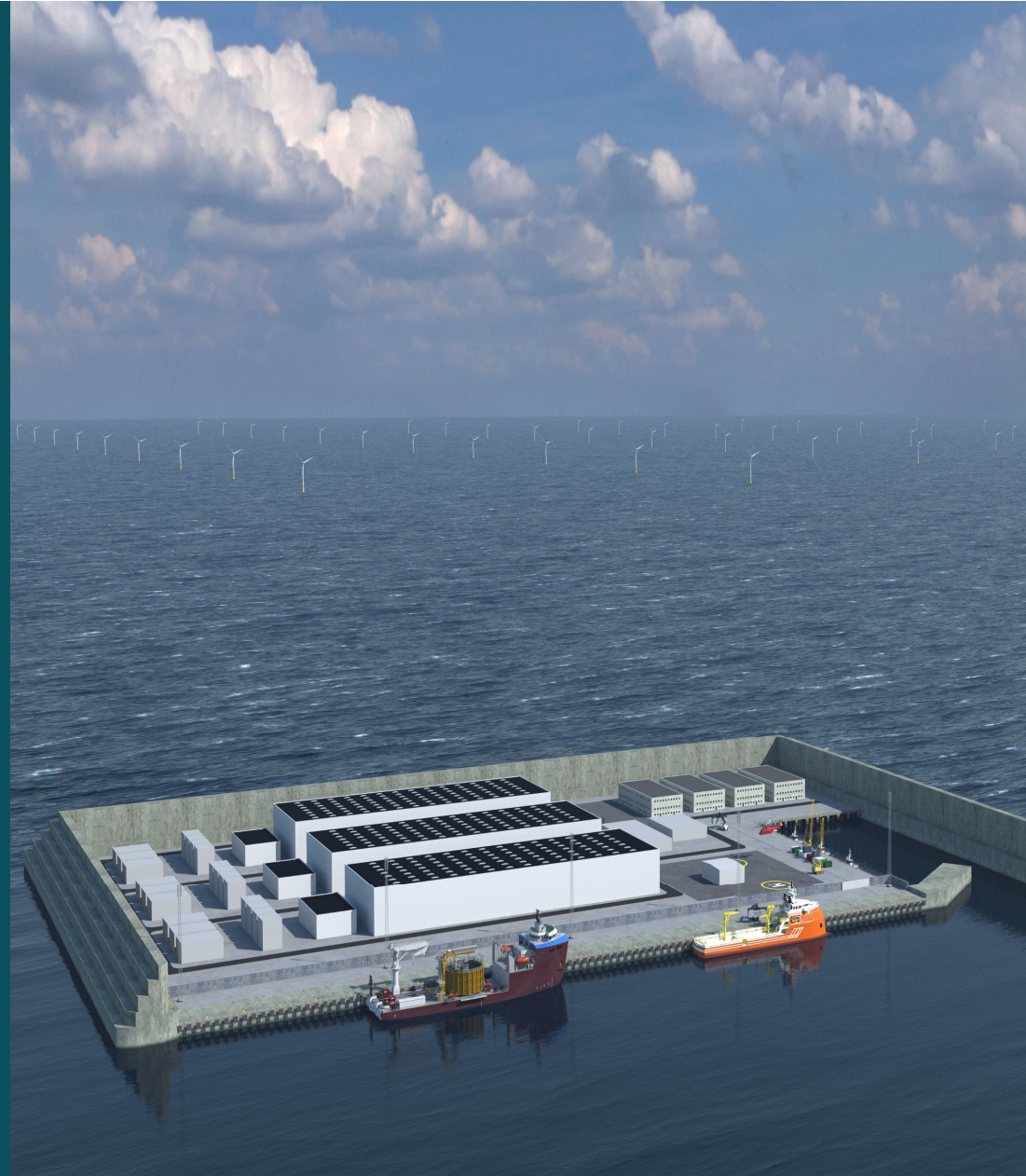


Issues to tackle:

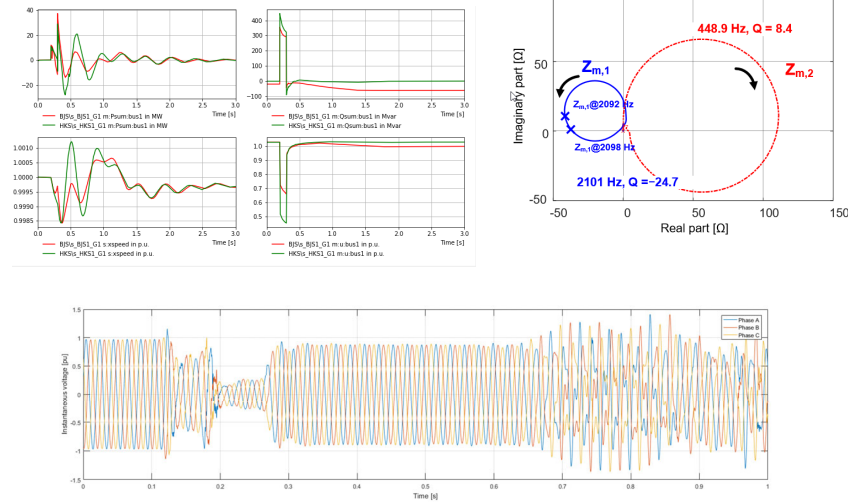
- All existing issues
- Introducing additional equipment in an extreme environment
- Flexible controls and equipment: How should we invest in an uncertain future?
- Multi-vendor interoperability at a new level of complexity

ANALYTICAL TOOLS AND MODELS

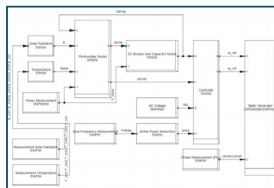
For electrical design of energy hubs



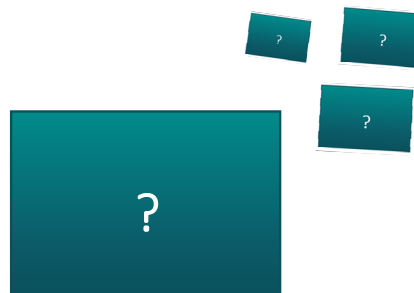
Analytical methods



Simulation models

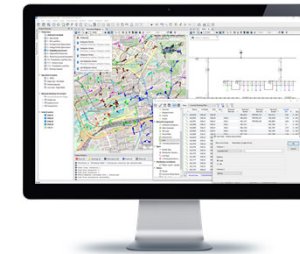


Open-source
generic models



Vendor-specific
black box models

Platform



Simulation model specification based on grid code


[Home](#)
[CO2 & ECF](#)
[Data](#)
[Files](#)
[Outlooks](#)
[Registers](#)
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[Publications](#)
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[News & Events](#)
[Stakeholder](#)
[Stakeholder Committee](#)
[Implementation](#)
[Development History](#)
[Consultations](#)

Requirements for Generators

The latest CO2 on Requirements for Generators is harmonising standards that generators must respect to connect to the grid. These harmonised standards across Europe will boost the market of generation technology and increase competitiveness.

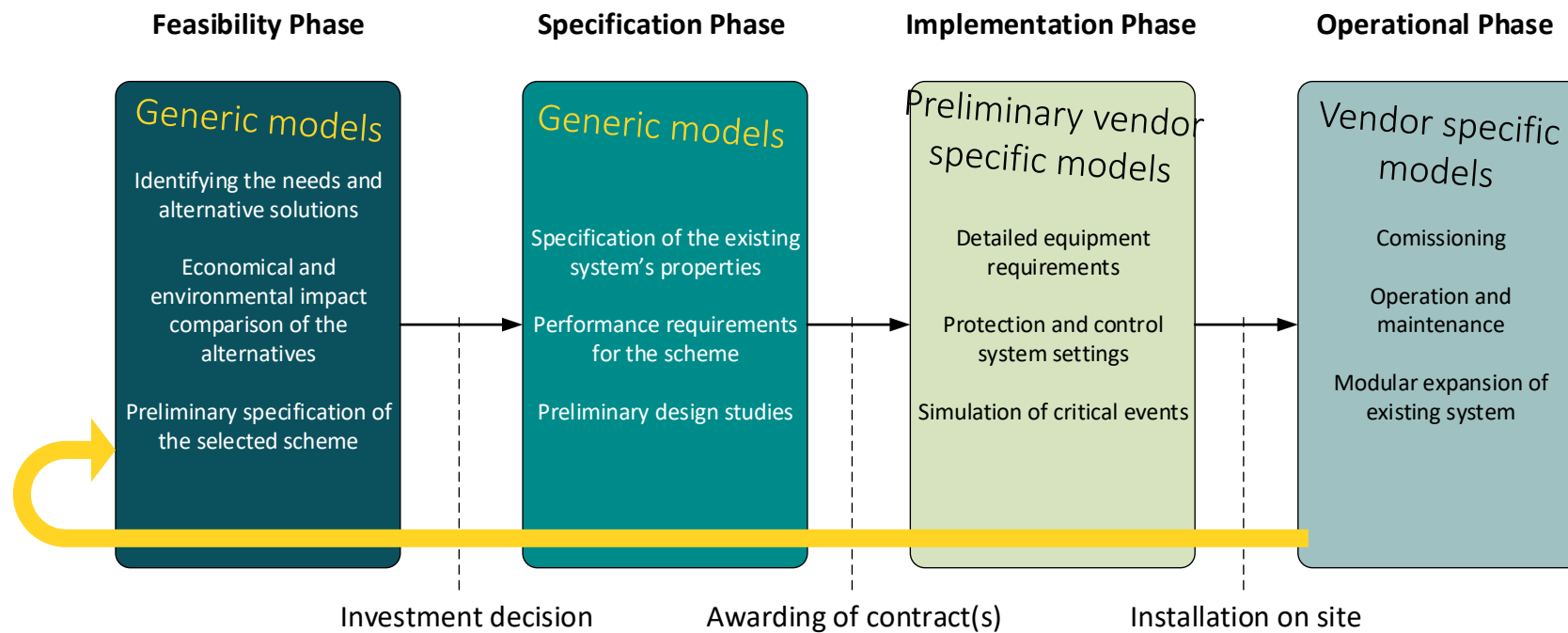
current status here

find the guidelines

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ANALYTICAL TOOLS AND MODELS

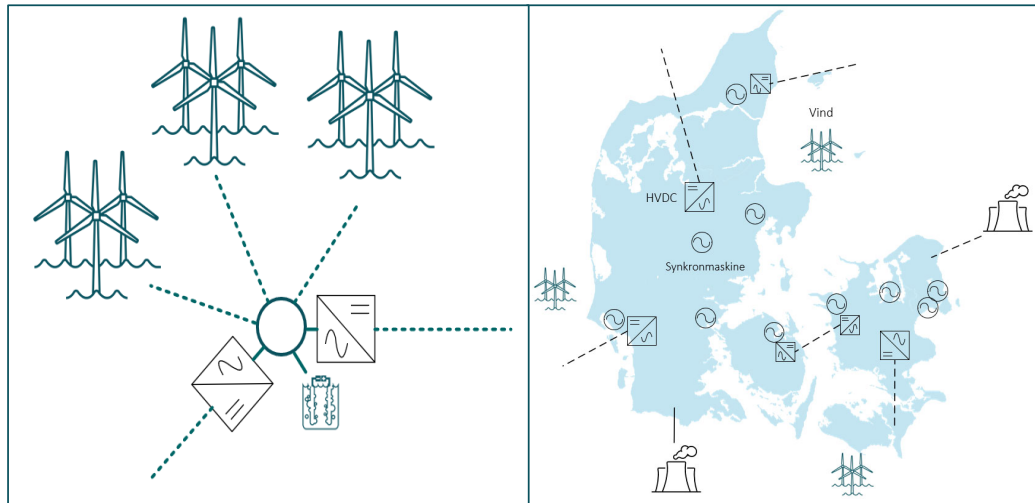
Simulation model availability



Analytical tools and models

All models available

Model availability issues



- All necessary models can be specified from the very beginning
- A limited number of plants, at least in the beginning, makes other types of analyses possible than for onshore systems.

Task given:

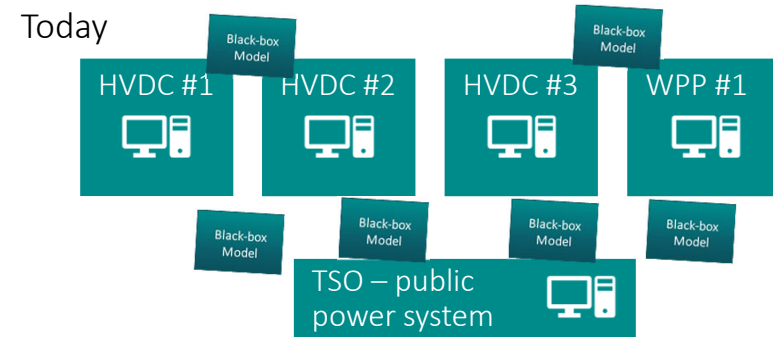
- Plan, design and operate:
- offshore power system
 - landing facilities
 - Interconnectors



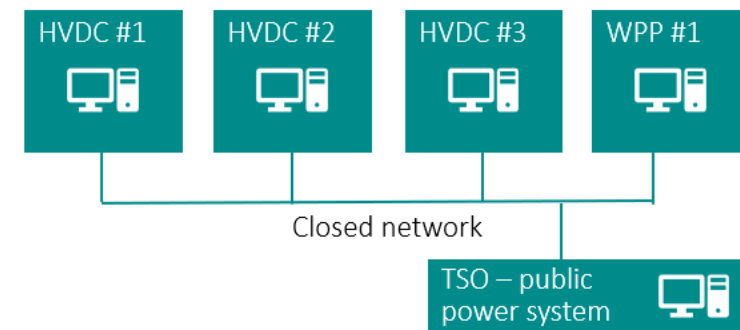
ANALYTICAL TOOLS AND MODELS

Data and model sharing – an absolute necessity for interoperability

- Each plant owner needs access to detailed EMT models to validate plant performance
- EMT models cannot typically be shared between relevant parties due to IPR (at least it is complicated and time-consuming)
- New system design platforms, enabling data and model sharing, are needed
 - a need to share models of plant n with plant owner $n+1,2,3,\dots$



Future



ANALYTICAL TOOLS AND MODELS

Data and model sharing – an absolute necessity for interoperability

- Each plant owner needs access to detailed EMT models to validate plant performance
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- New system design platforms, enabling data and model sharing, are needed
 - a need to share models of plant n with plant owner n+1,2,3,...

APPENDIX 1.B

REQUIREMENTS FOR GENERATORS (RFG) – SIMULATION MODEL REQUIREMENTS

This is a translation. In case of inconsistencies, the Danish version applies.

A	Public version	LAN CFJ CSH	JMI	MPO HAB KDL JGA VLA JKW	SBN PHT	15 May 2018
REV.	DESCRIPTION	PREPARED	CHECKED	REVIEWED	APPROVED	DATE

ENERGINET

Energinet
Tønne Kjaersvej 65
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info@energinet.dk
CVR no. 28 98 06 71

Date:
13 November 2018

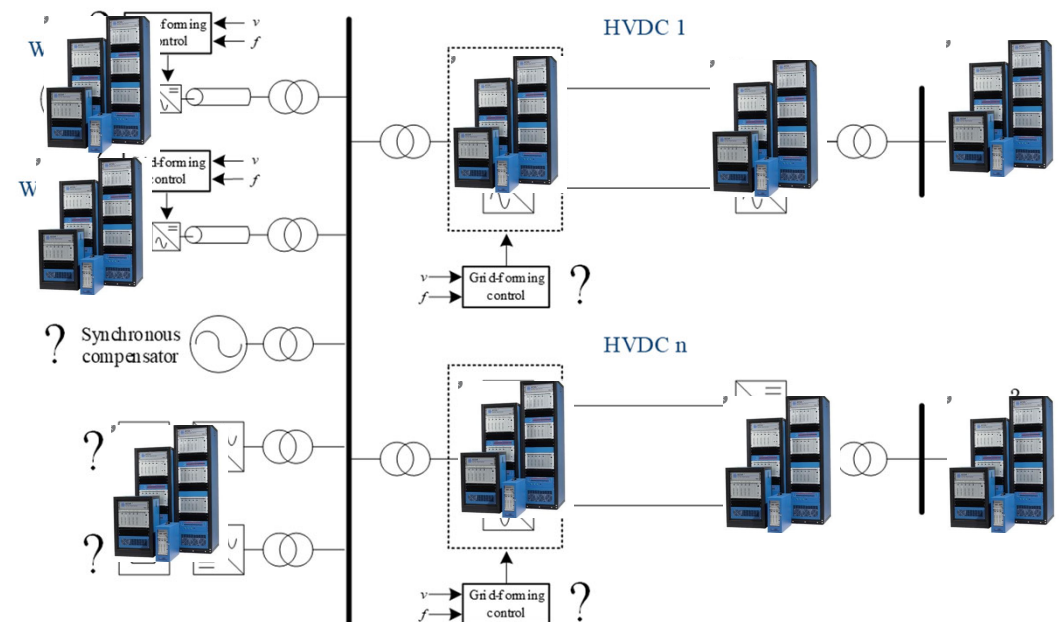
Author:
LAN/CFJ/CSH

- The EMT model must represent all components, control systems and protection systems relevant for EMT analyses.
- All relevant function settings in the generation facility's control system that are relevant for EMT analyses and that can be changed either locally or remotely must appear as available parameters in the simulation model. The scope of the delivery must be approved by the transmission system operator.

ANALYTICAL TOOLS AND MODELS

Data and model sharing – an absolute necessity

- With today's model quality, HIL- and SIL-based simulations will be needed to support offline simulations
- HIL and SIL make parallel work by several vendors possible (and handle IPR'-issues)
- A real-time environment quickly becomes complex and eventually unmanageable for energy hub type systems



THANK YOU FOR
YOUR ATTENTION

