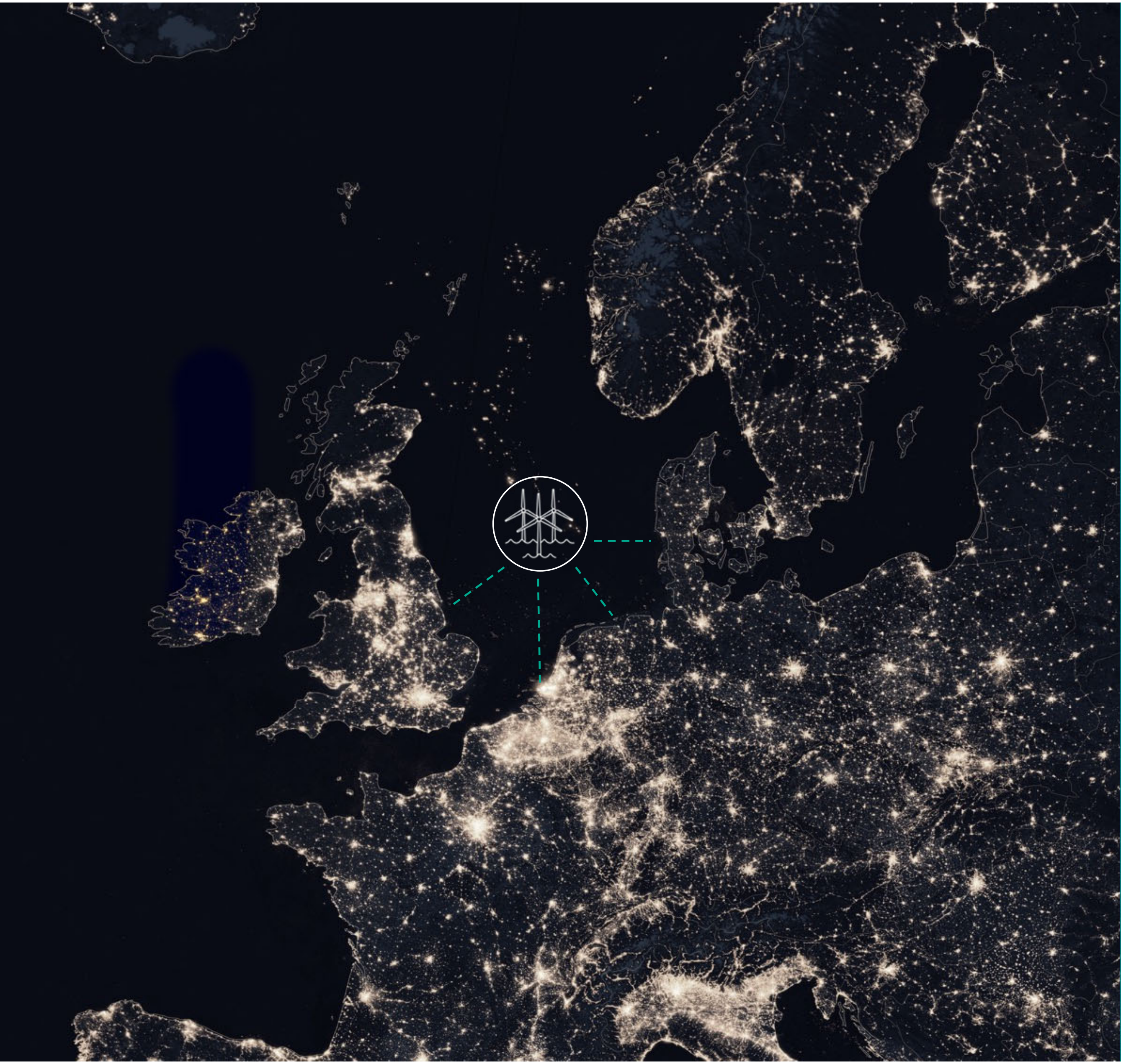


PLANNING AND DESIGN OF DENMARK'S FUTURE ENERGY ISLANDS

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

Christian Frank Flytkjær

Senior Manager, PhD

CFJ@energinet.dk

CONTENTS

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.*

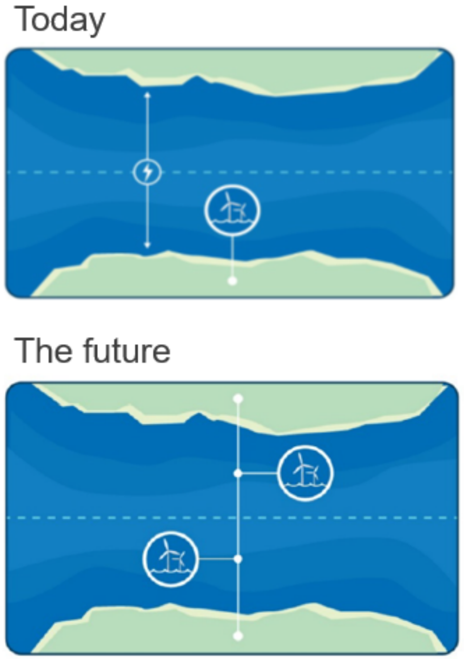

EUROPEAN COMMISSION

Brussels, 19.11.2020
COM(2020) 741 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

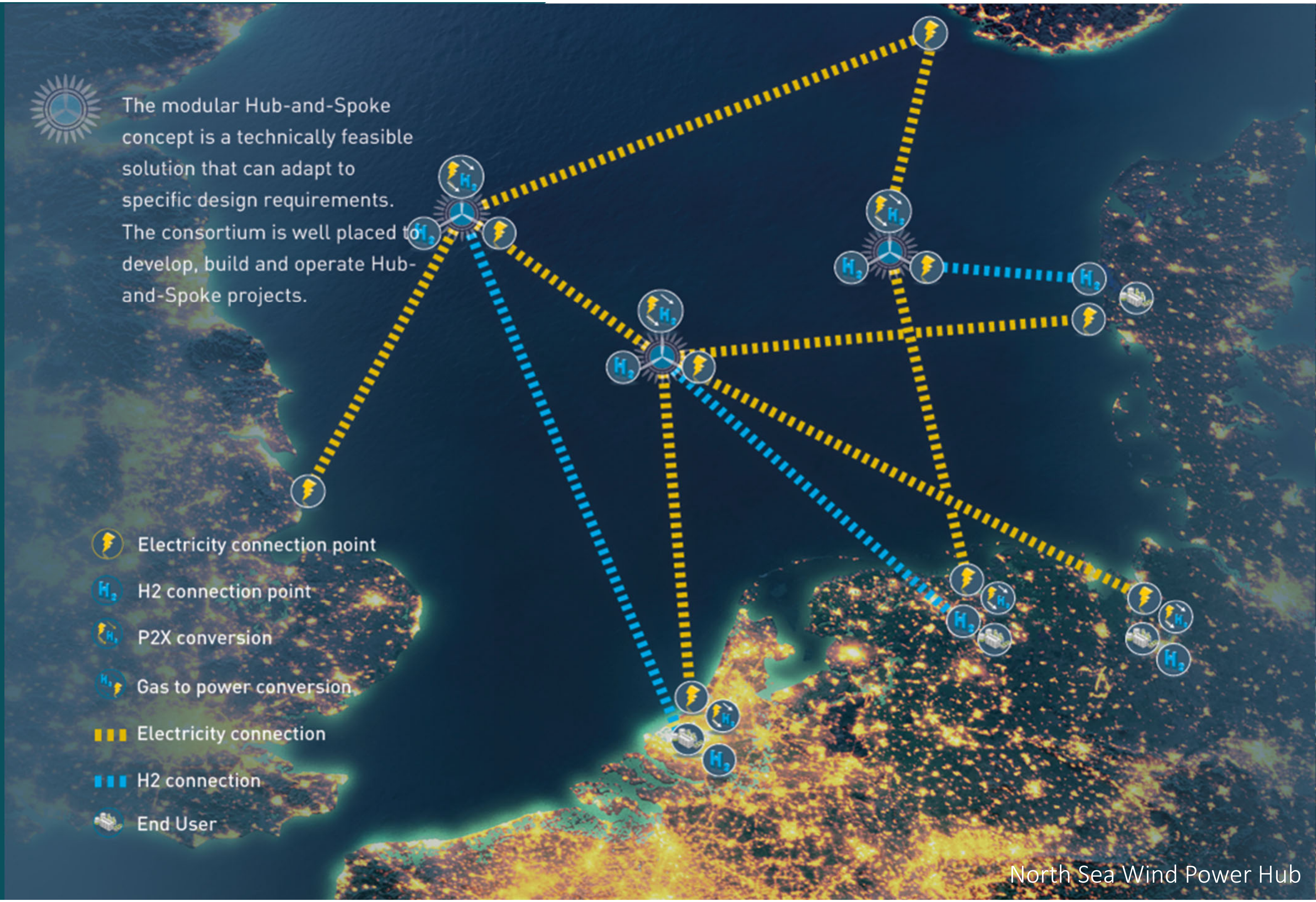
An EU Strategy to harness the potential of offshore renewable energy for a climate neutral future

{SWD(2020) 273 final}

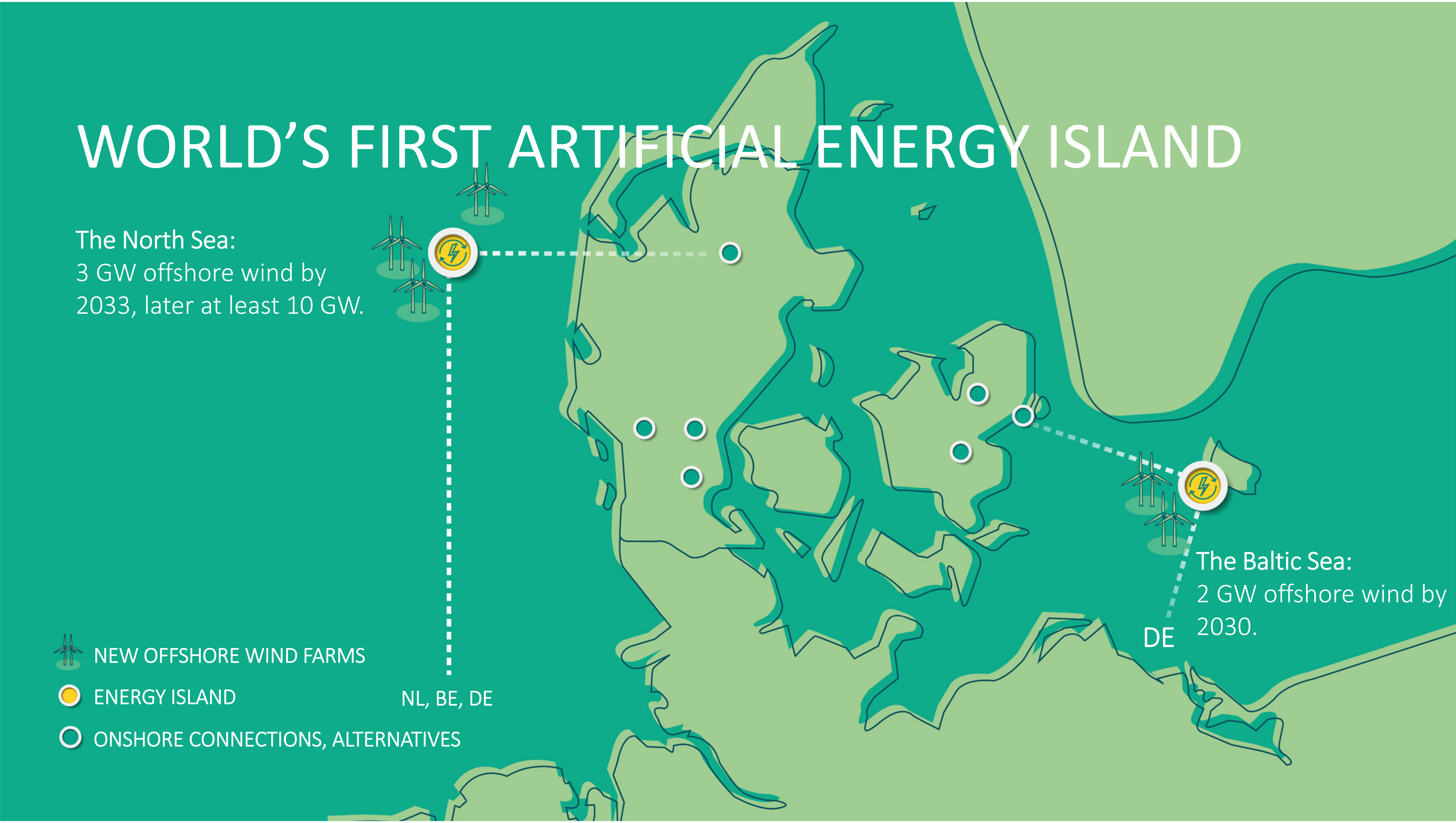


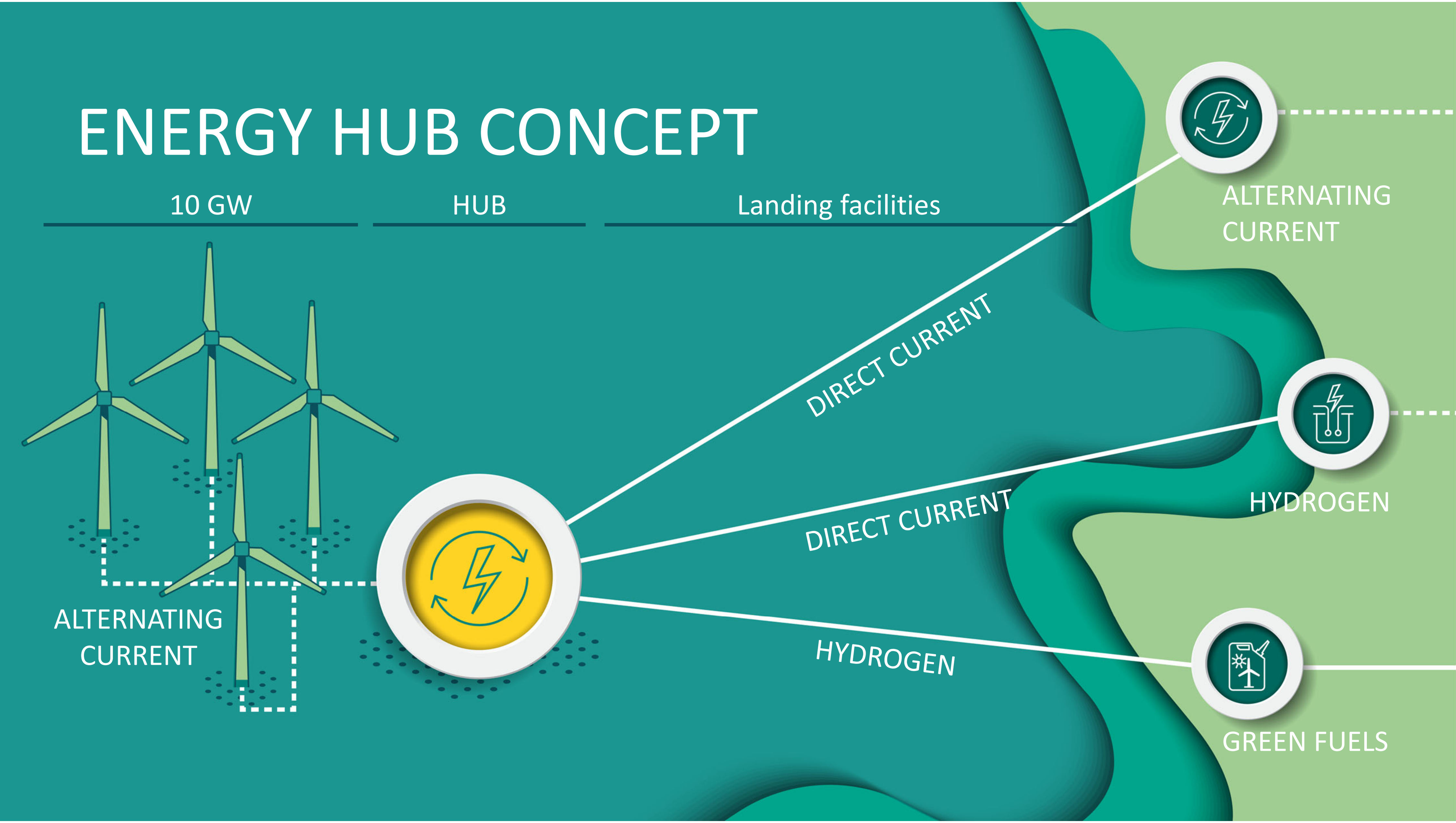
An EU strategy to harness the potential of offshore renewable energy for a climate neutral future.

A POSSIBLE VERSION OF THE FUTURE



WORLD'S FIRST ARTIFICIAL ENERGY ISLAND




ENERGY HUB CONCEPT
10 GW
HUB
Landing facilities
ALTERNATING CURRENT
DIRECT CURRENT
DIRECT CURRENT
HYDROGEN
ALTERNATING CURRENT
HYDROGEN
GREEN FUELS

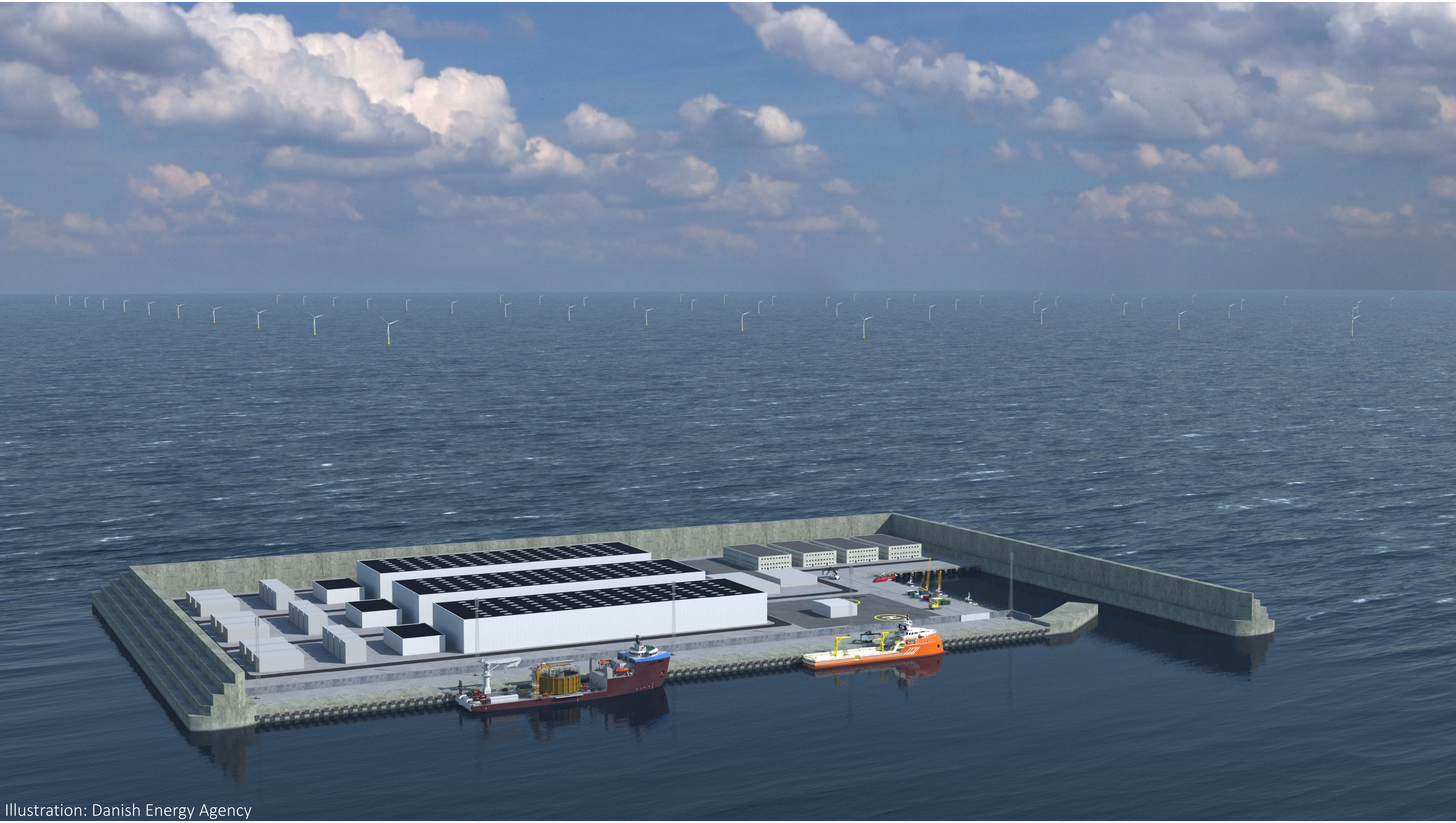
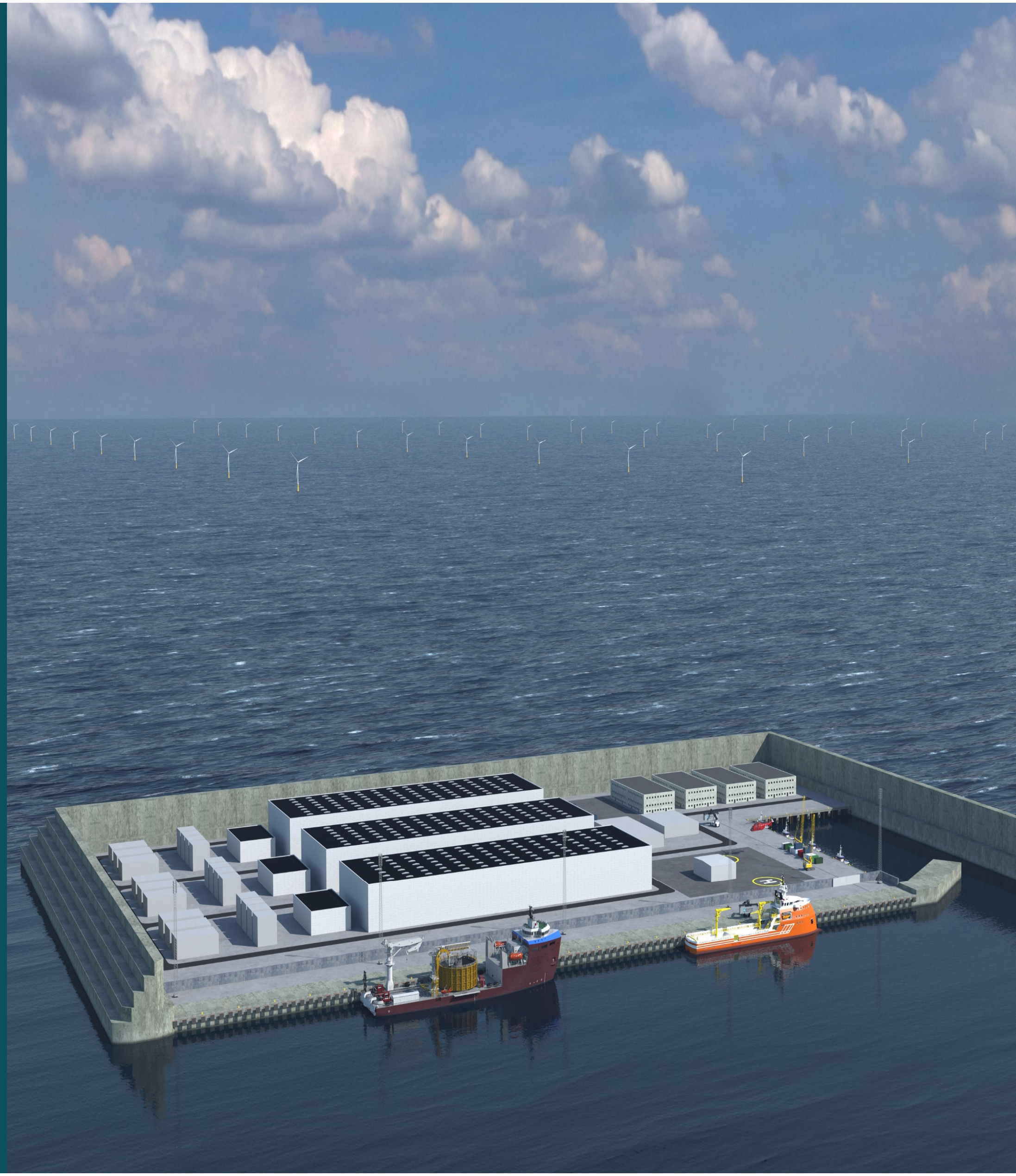
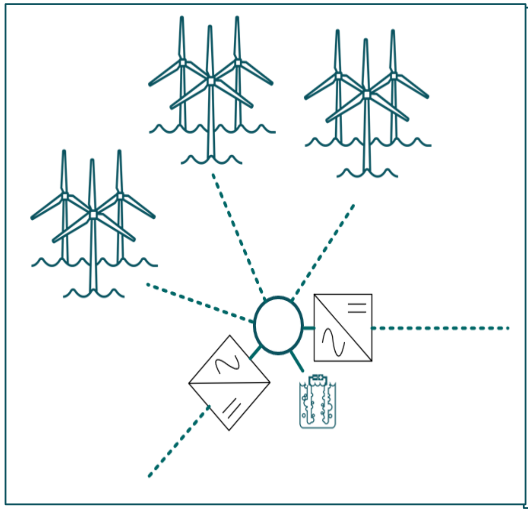


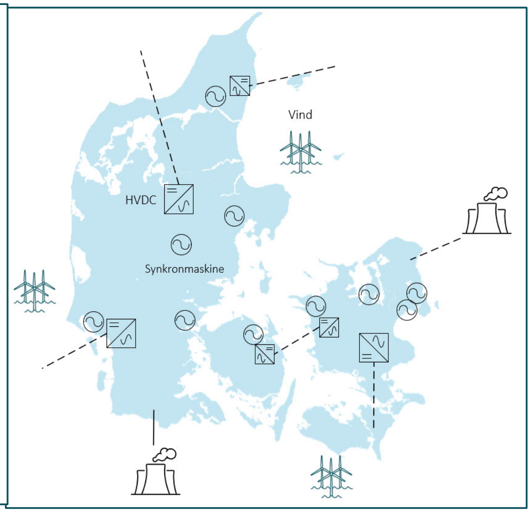
Illustration: Danish Energy Agency

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:

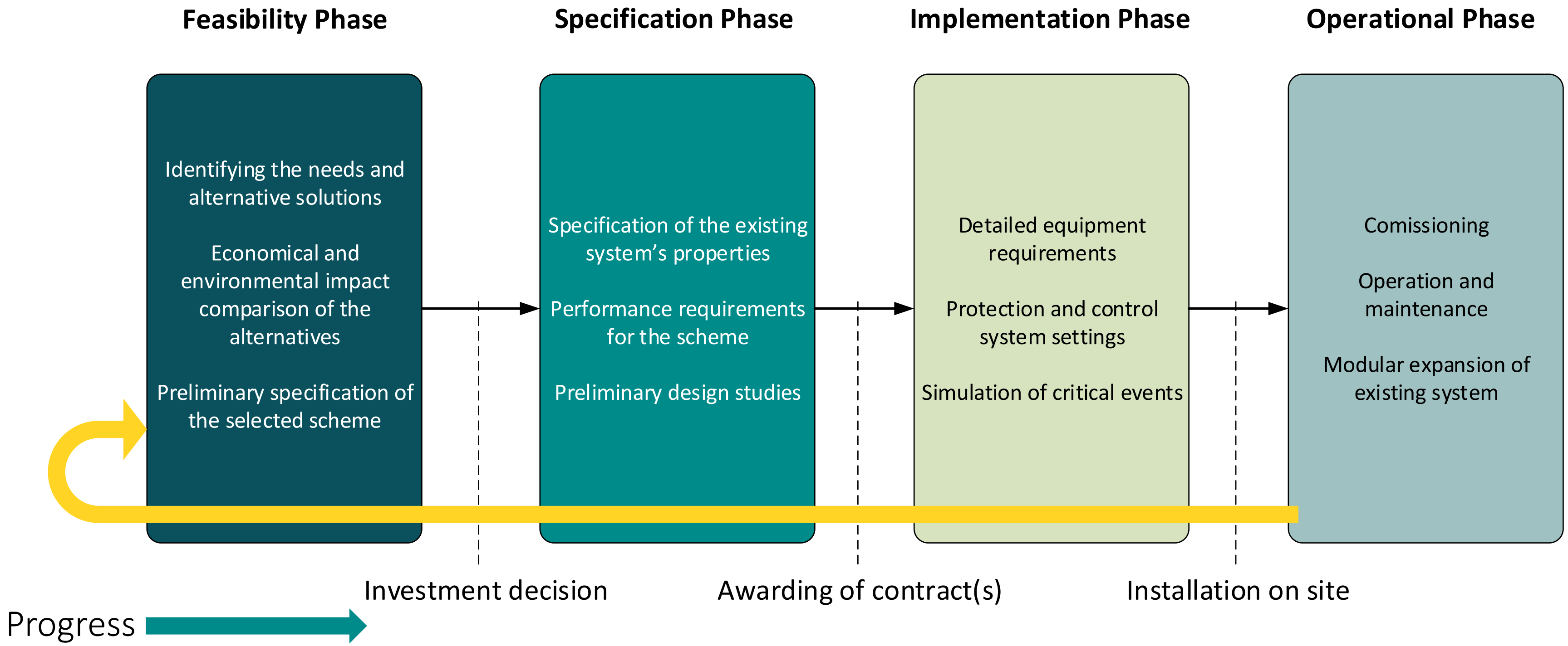
- *Measure every electron out there*
- Quantify and qualify them
- Share data to the highest extend possible

PROJECT PHASES

Phases are typically mostly based on experience

Two main differences

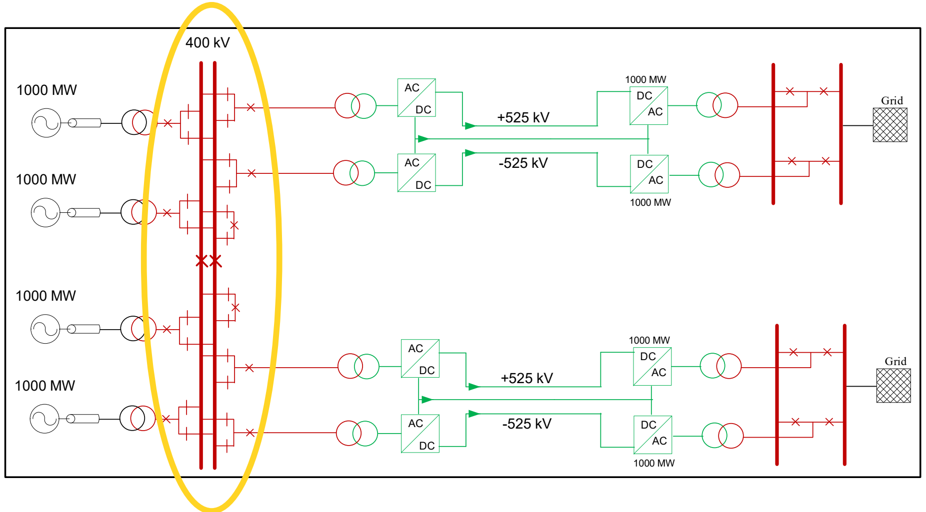
- Little experience for each phase to build on
- The linear process becomes cyclic



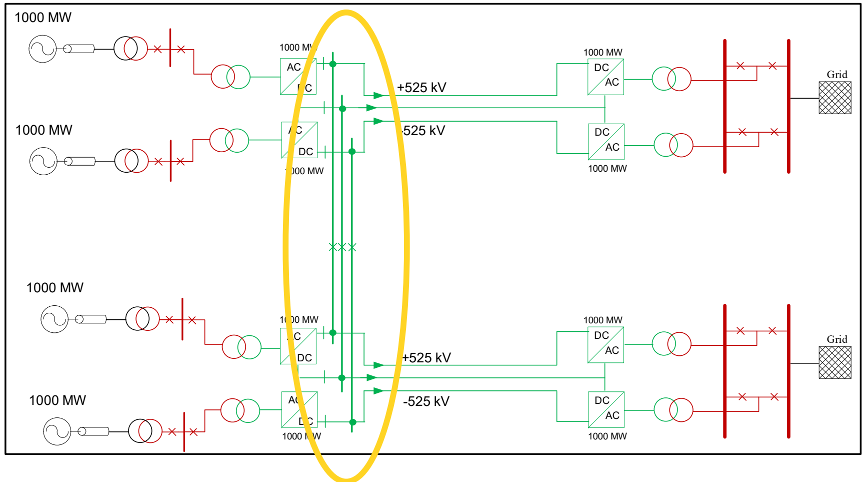
ENERGINET

TOPOLOGY CANDIDATES

The largest decision in the feasibility phase



AC-hub



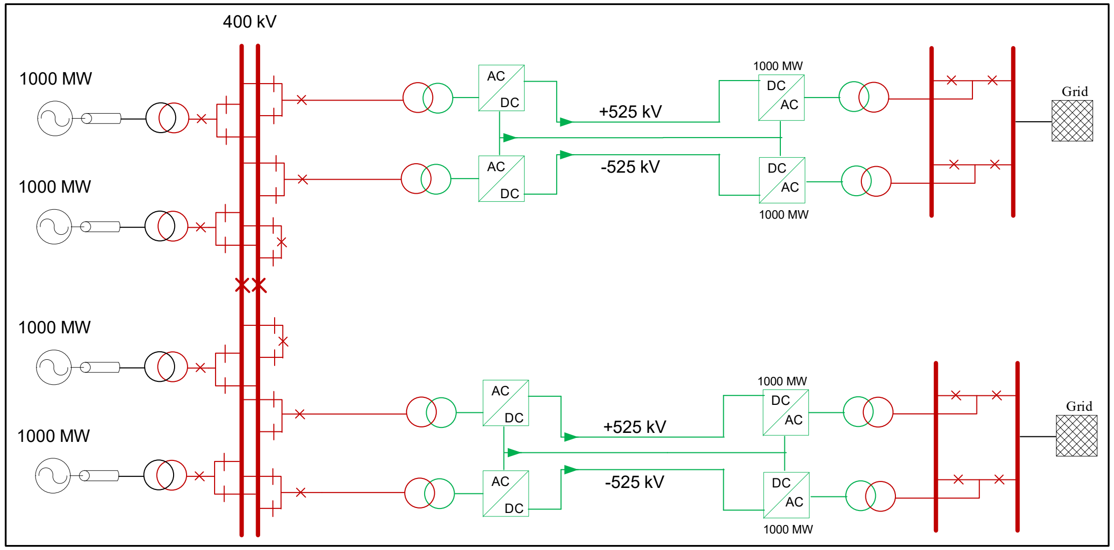
DC-hub

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.

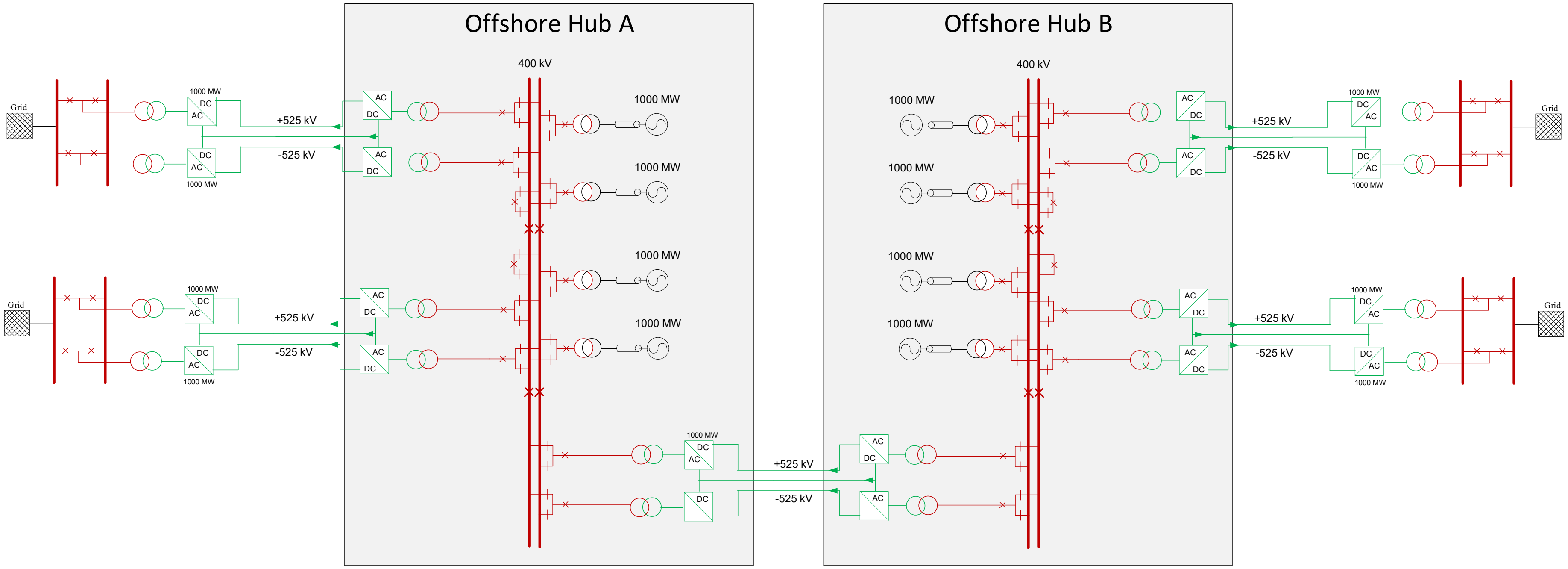


ENERGINET

TOPOLOGY CANDIDATES

Connection to other hubs or countries

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



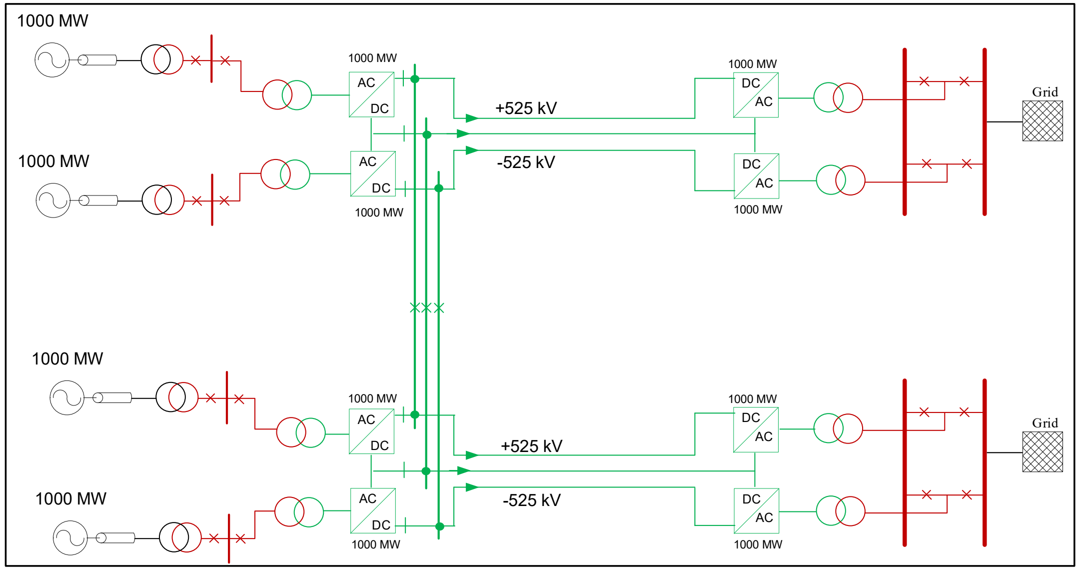
ENERGINET

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.

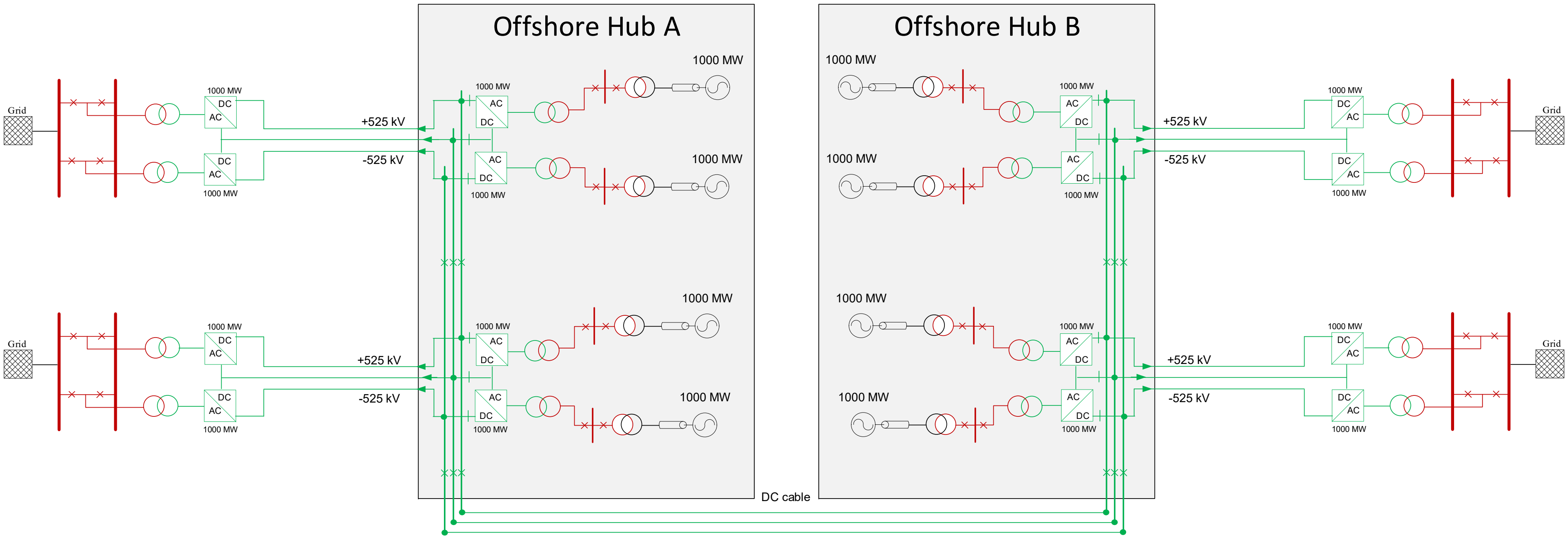


ENERGINET

TOPOLOGY CANDIDATES

Connection to other hubs or countries

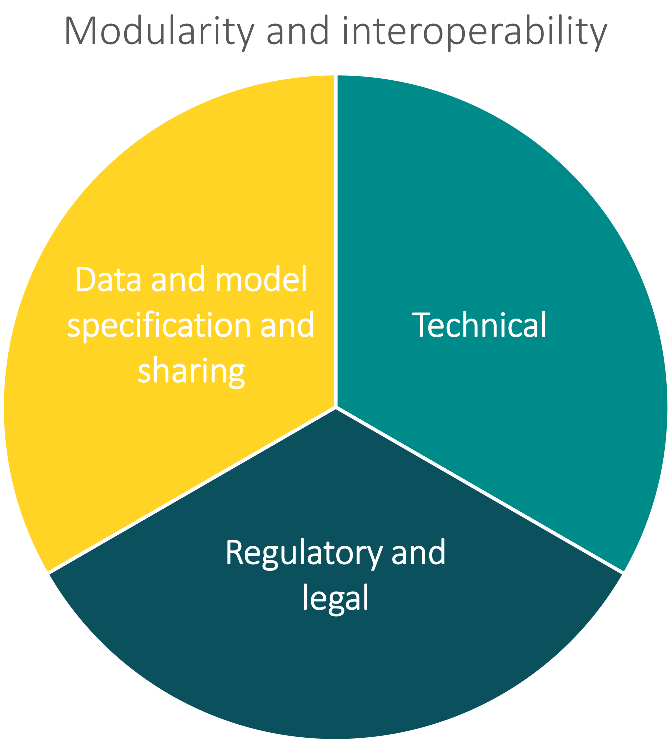
- Connecting other hubs requires a DC connection only
- Connecting hubs affects all DC-system controllers significantly



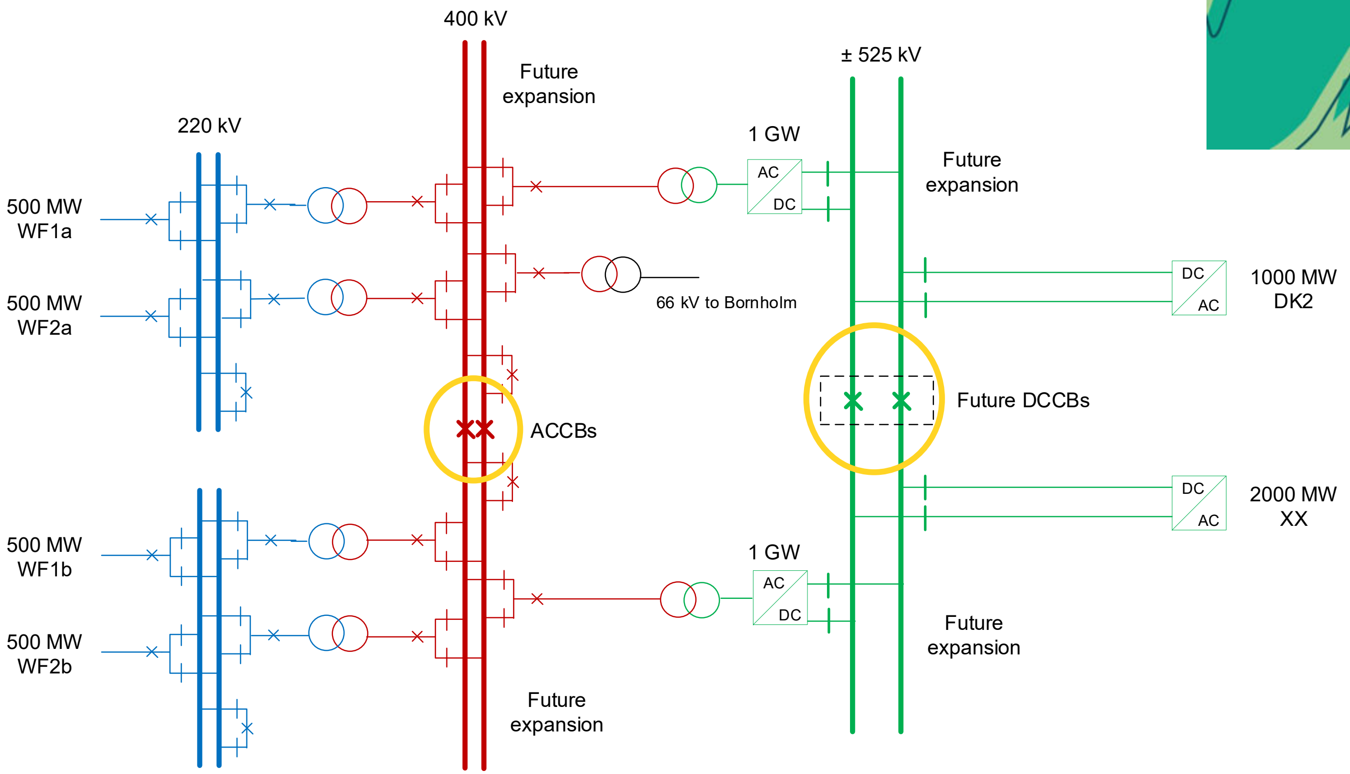
MODULARITY BY DESIGN

“Energy islands should be expandable”

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



MIX OF TOPOLOGIES AS A LEARNING EXPERIENCE?

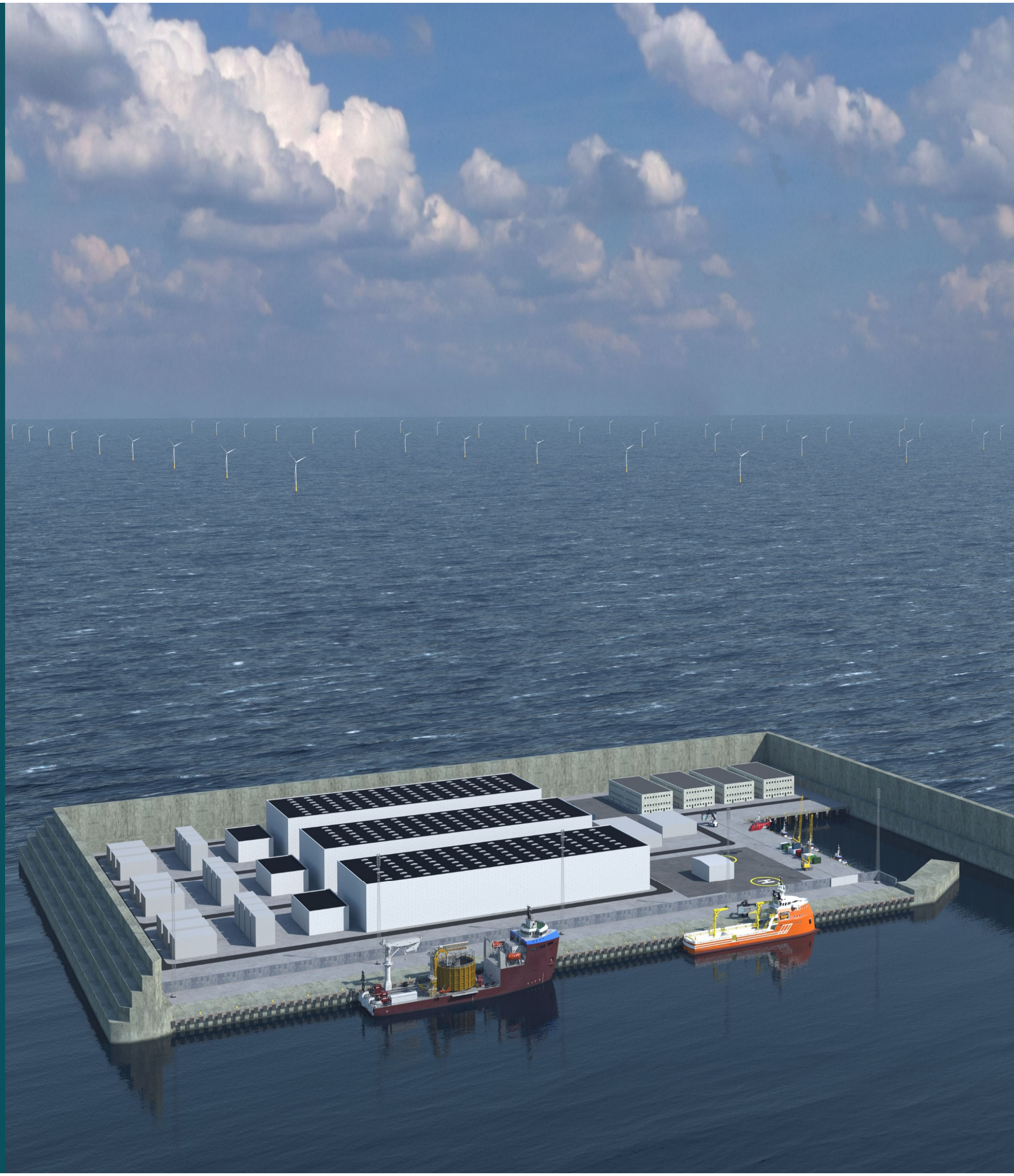


An investment in the future?

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

TECHNICAL CHALLENGES

To overcome

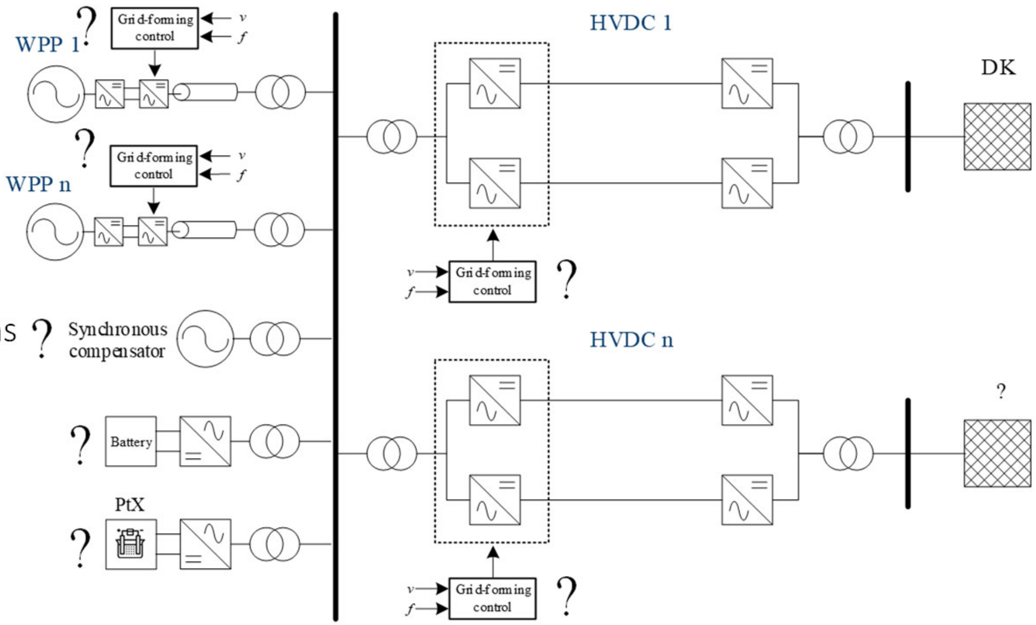


ENERGINET

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

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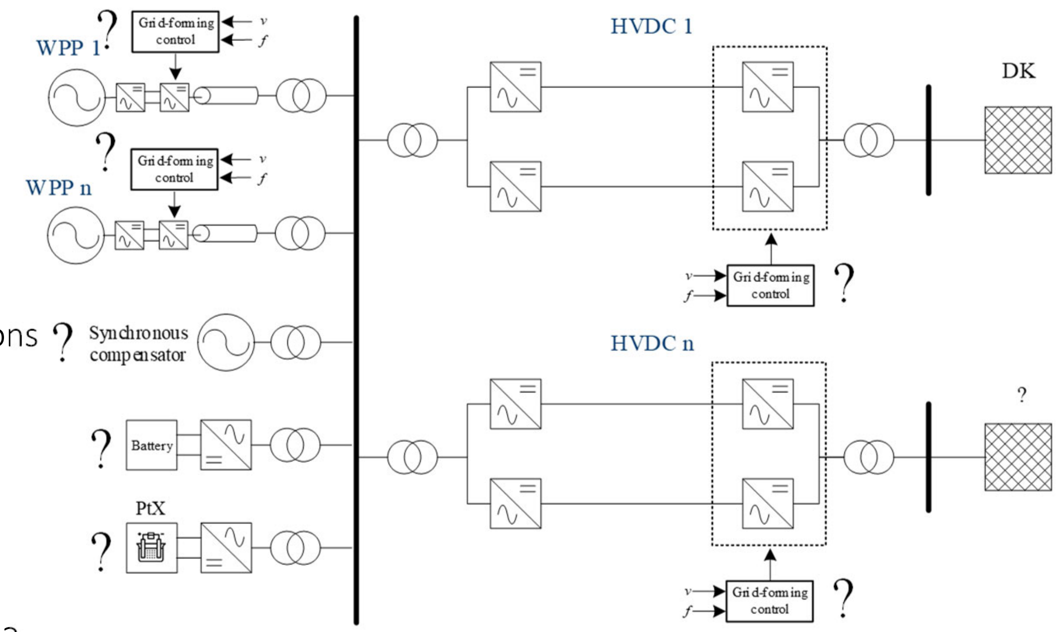
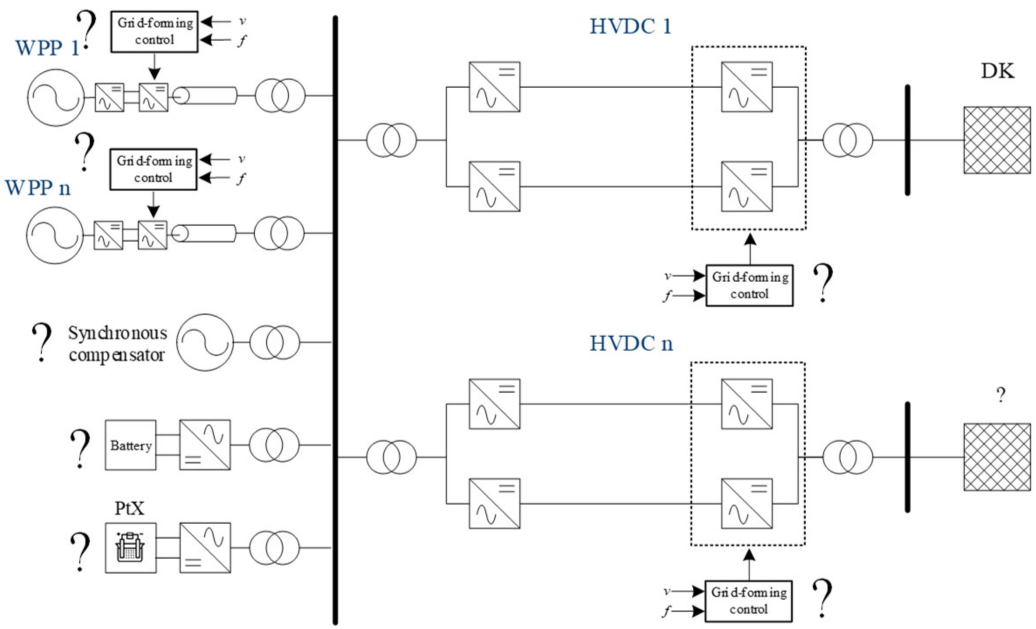


HVDC-BASED WIND POWER LANDING

AC hub – specifying a new offshore power system

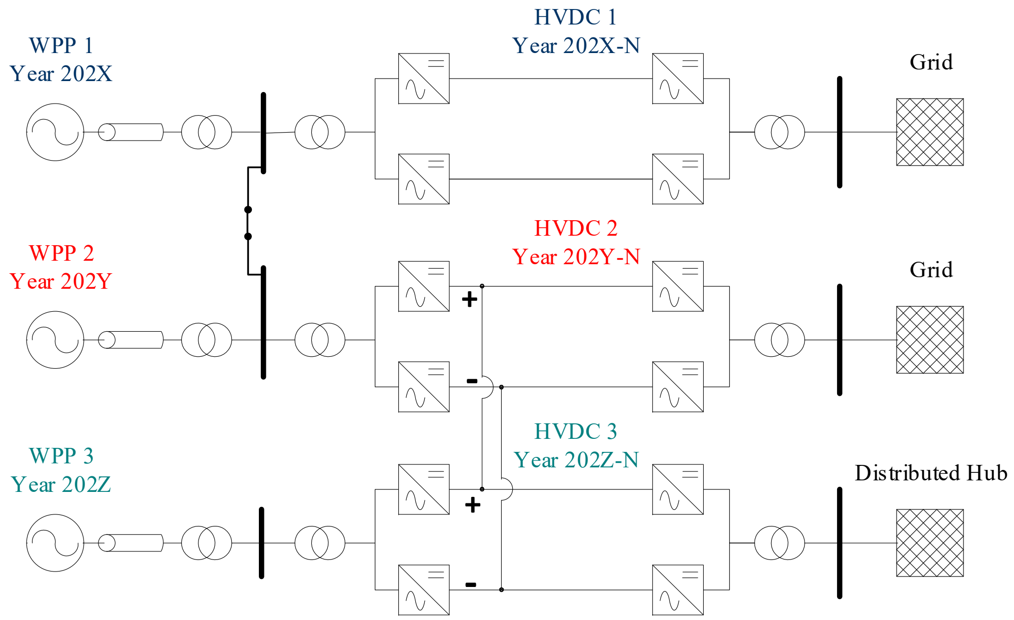
- Adding rotating mass – good idea, bad idea?
- Protection philosophy
- Power quality management
- Hub monitoring and early warning early prevention systems
- … and probably many more.



HVDC-BASED WIND POWER LANDING

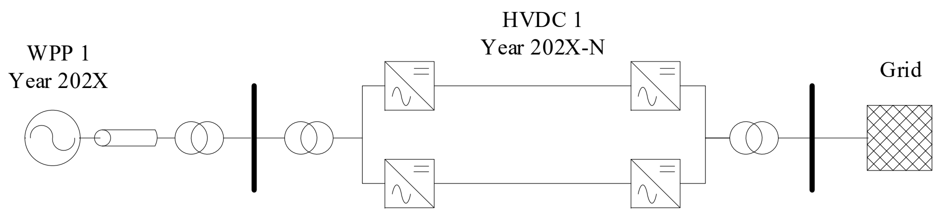
DC hub – specifying not yet proven technology

- 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

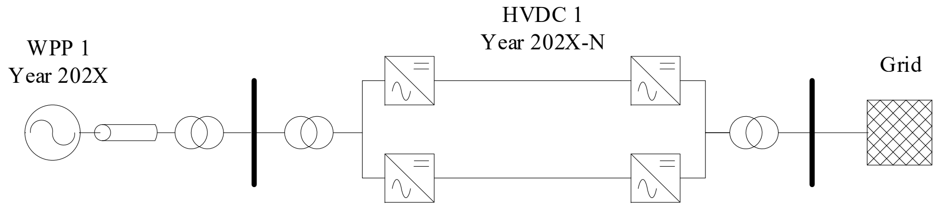


Issues to tackle:

- 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 L

Expandability



Knall auf hoher See

Ökostrom Elektrotechniker rätseln: Die Konverterstation eines Offshore-Windparks schmorte 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 ausgeträumt.

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

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 Off-

nächsten Park, der schon im September ans Netz gehen soll? Trianel Windpark Borkum heißt er, gehört dem Stadtwerkeunternehmen 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.

Plattform Borwin Alpha

Eigentlich sollte Bard 1 Anfang Juni wieder Strom ans Festland liefern, dann Anfang Juli, dann im August. Jetzt traut man sich bei Tennet 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 HGÜ-Anlagen genannt, werden derzeit nur von drei Herstellern weltweit angeboten, und nur zwei haben bereits solche Gewerke für den Offshore-Einsatz tatsächlich gebaut: ABB und Siemens.

ABB war der erste Anbieter von Offshore-HGÜ-Anlagen überhaupt, und ausge-

rol

systems

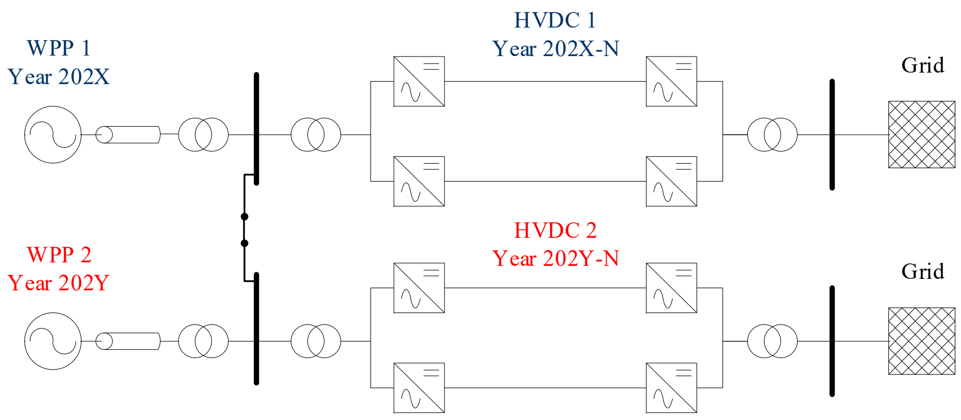
- A series of problems have been encountered
- Existing solutions are known from Germany, among others

Der Spiegel Wirtschaft24.08.2014

ENERGINET

HVDC-BASED WIND POWER LANDING

Expandability

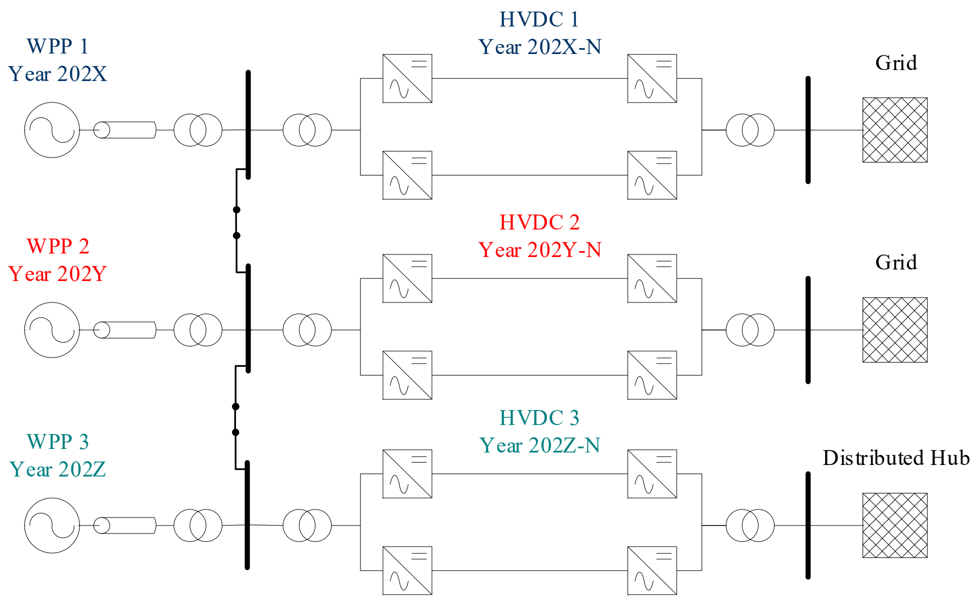


Issues to tackle:

- 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



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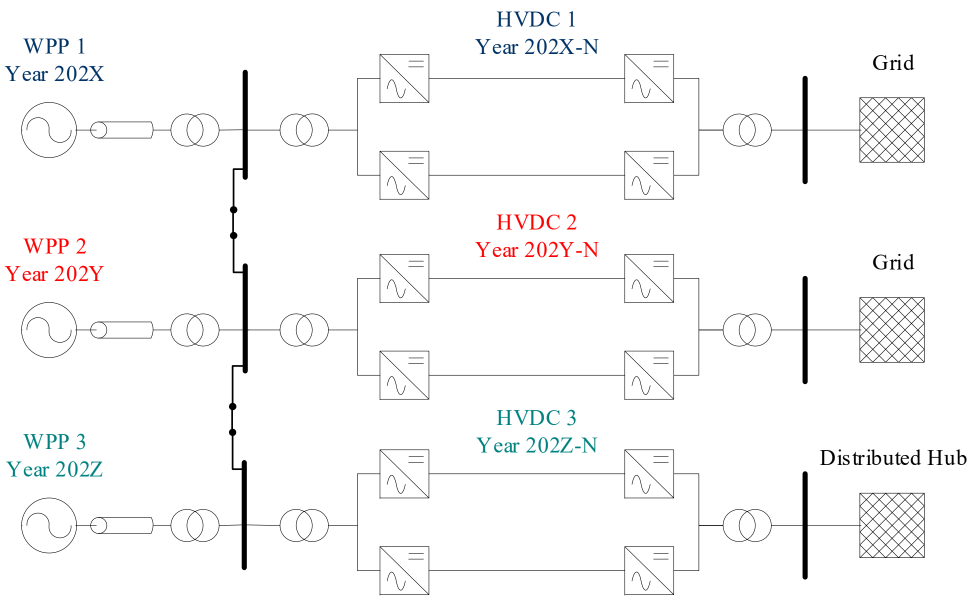
HVDC-BASED WIND POWER LANDING

Expandability

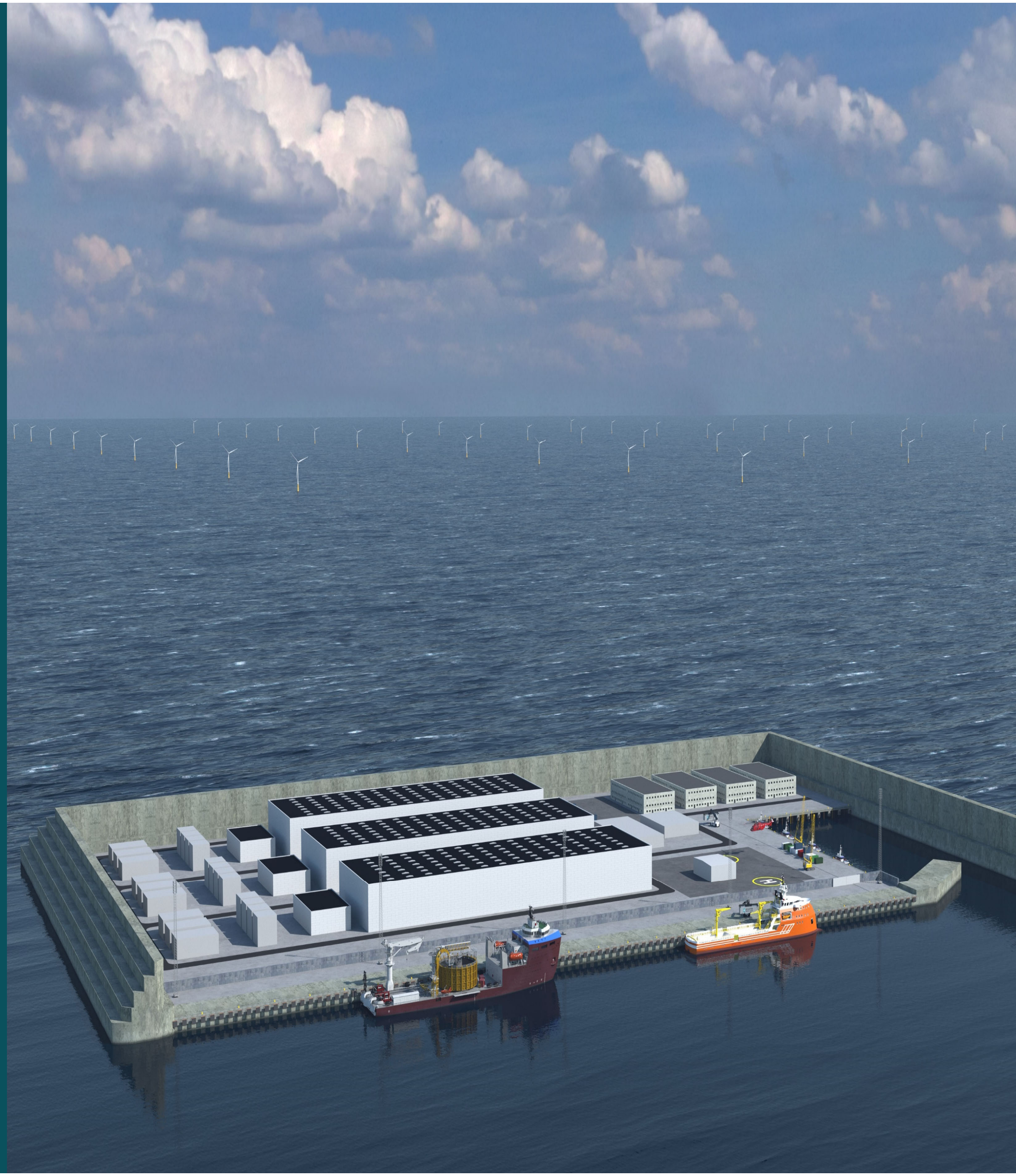


Issues to tackle:

- 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

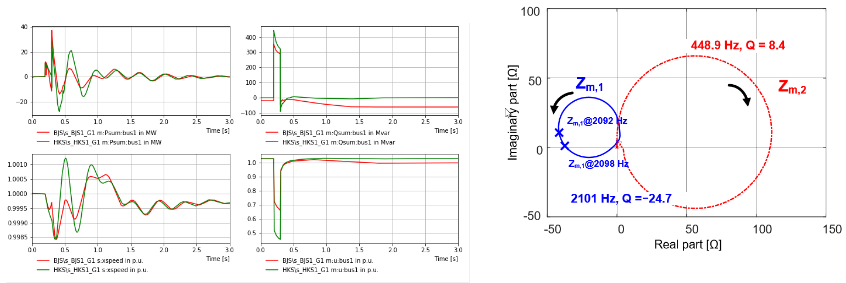
ANALYTICAL TOOLS AND MODELS

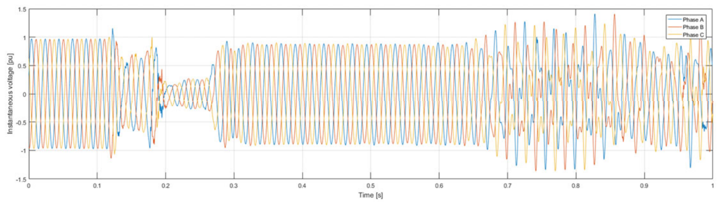
For electrical design of energy hubs



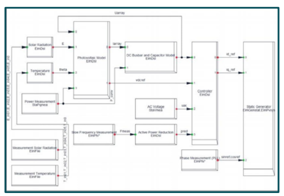
ANALYTICAL TOOLS AND MODELS FOR ELECTRICAL DESIGN OF ENERGY HUBS

Analytical methods

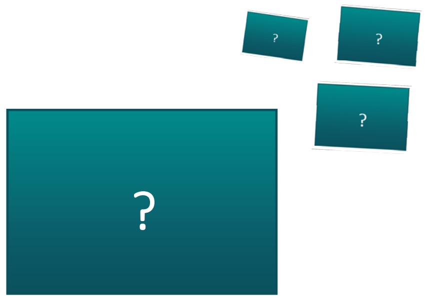




Simulation models



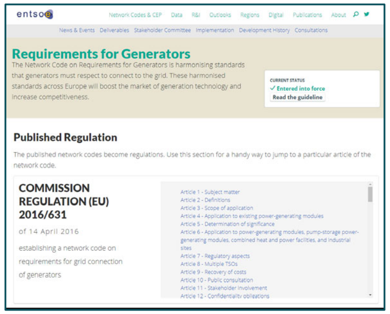
Open-source generic models



Vendor-specific black box models

Platform

Simulation model specification based on grid code



entsoe

Network Codes & CEP Data R&I Outlooks Regions Digital Publications About

News & Events Deliverables Stakeholder Committee Implementation Development History Consultations

Requirements for Generators

The Network Code 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
✓ Entered into force
Read the guideline

Published Regulation

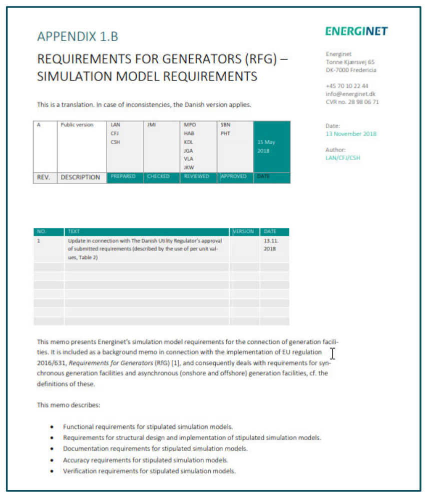
The published network codes become regulations. Use this section for a handy way to jump to a particular article of the network code.

COMMISSION REGULATION (EU) 2016/631

of 14 April 2016

establishing a network code on requirements for grid connection of generators

Article 1 - Subject matter
Article 2 - Definitions
Article 3 - Scope of application
Article 4 - Application to existing power-generating modules
Article 5 - Determination of significance
Article 6 - Application to power-generating modules, pump-storage power-generating modules, combined heat and power facilities, and industrial sites
Article 7 - Regulatory aspects
Article 8 - Multiple TSOs
Article 9 - Recovery of costs
Article 10 - Public consultation
Article 11 - Stakeholder involvement
Article 12 - Confidentiality obligations



APPENDIX 1.B

REQUIREMENTS FOR GENERATORS (RFG) – SIMULATION MODEL REQUIREMENTS

ENERGINET

Energinet
Tonne Kjærsvej 65
DK-7000 Fredericia

+45 70 10 22 44
info@energinet.dk
CVR no. 28 98 06 71

Date:
13 November 2018

Author:
LAN/CFJ/CSH

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

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

NO.	TEXT	VERSION	DATE
1	Update in connection with The Danish Utility Regulator's approval of submitted requirements (described by the use of per unit values, Table 2)		13.11. 2018

This memo presents Energinet's simulation model requirements for the connection of generation facilities. It is included as a background memo in connection with the implementation of EU regulation 2016/631, *Requirements for Generators* (RfG) [1], and consequently deals with requirements for synchronous generation facilities and asynchronous (onshore and offshore) generation facilities, cf. the definitions of these.

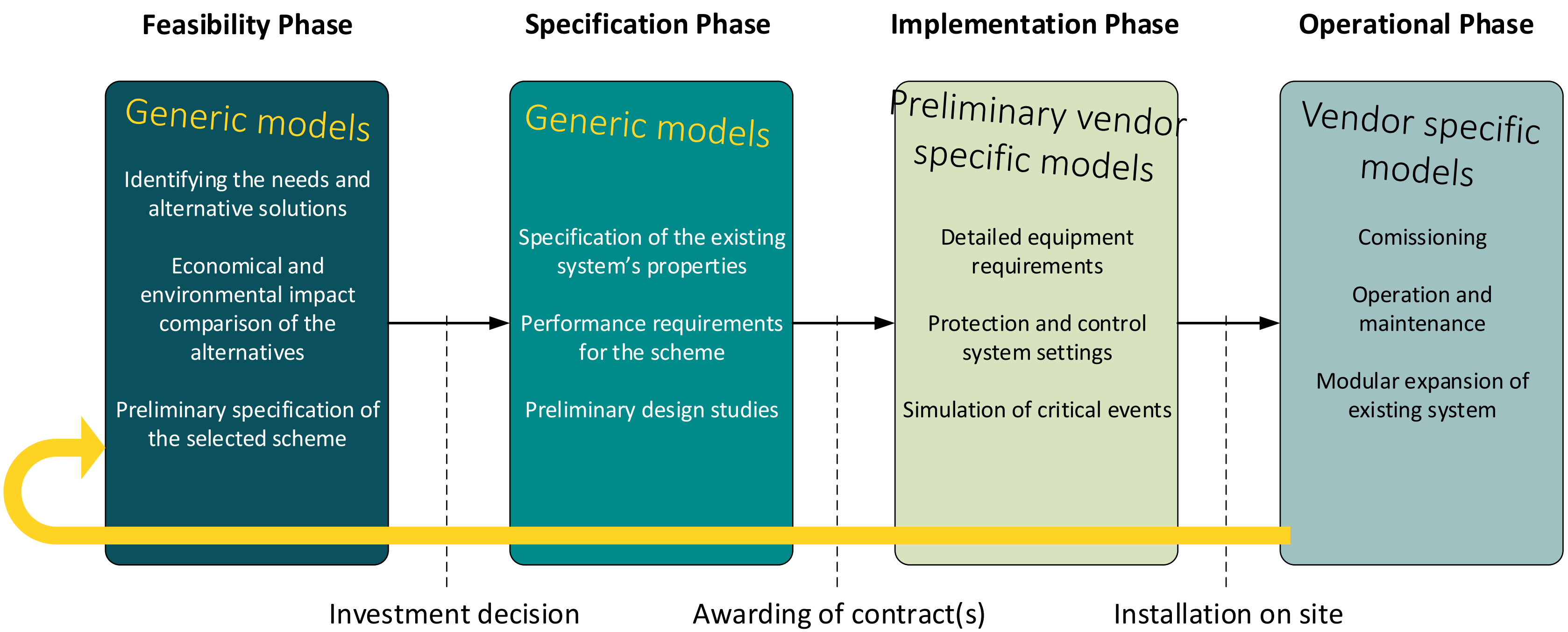
This memo describes:

- Functional requirements for stipulated simulation models.
- Requirements for structural design and implementation of stipulated simulation models.
- Documentation requirements for stipulated simulation models.
- Accuracy requirements for stipulated simulation models.
- Verification requirements for stipulated simulation models.

ENERGINET

ANALYTICAL TOOLS AND MODELS

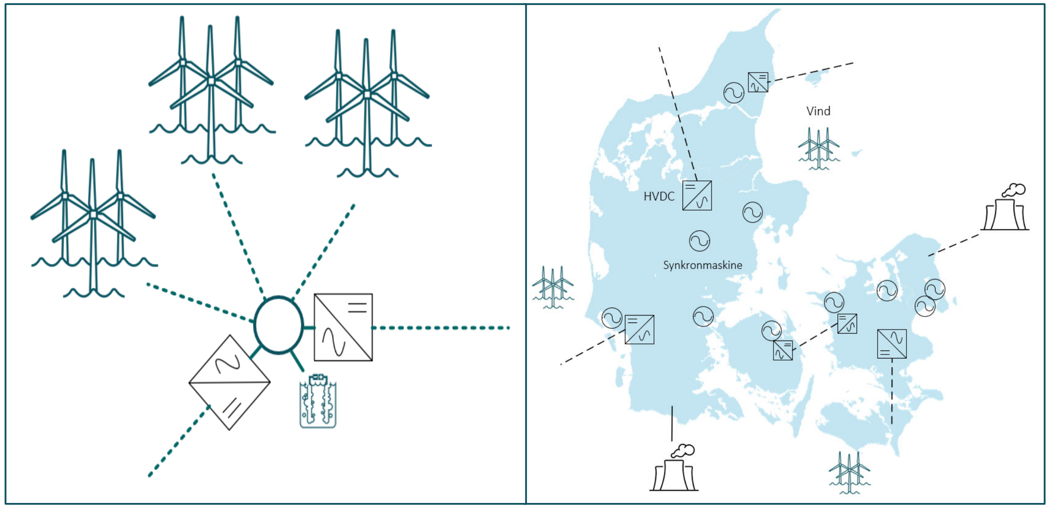
Simulation model availability



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:

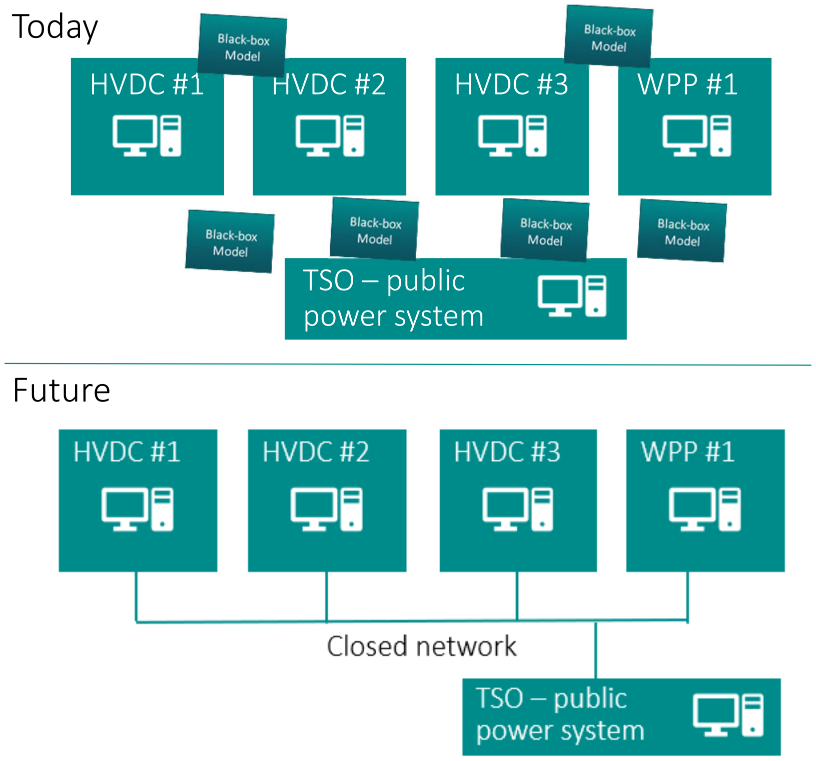
Plan, design and operate:

- 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,...



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SIMULATION MODEL REQUIREMENTS

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Tonne Kjærsvej 65
DK-7000 Fredericia

+45 70 10 22 44
info@energinet.dk
CVR no. 28 98 06 71

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Author:
LAN/CFJ/CSH

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REV.	DESCRIPTION	PREPARED	CHECKED	REVIEWED	APPROVED	DATE

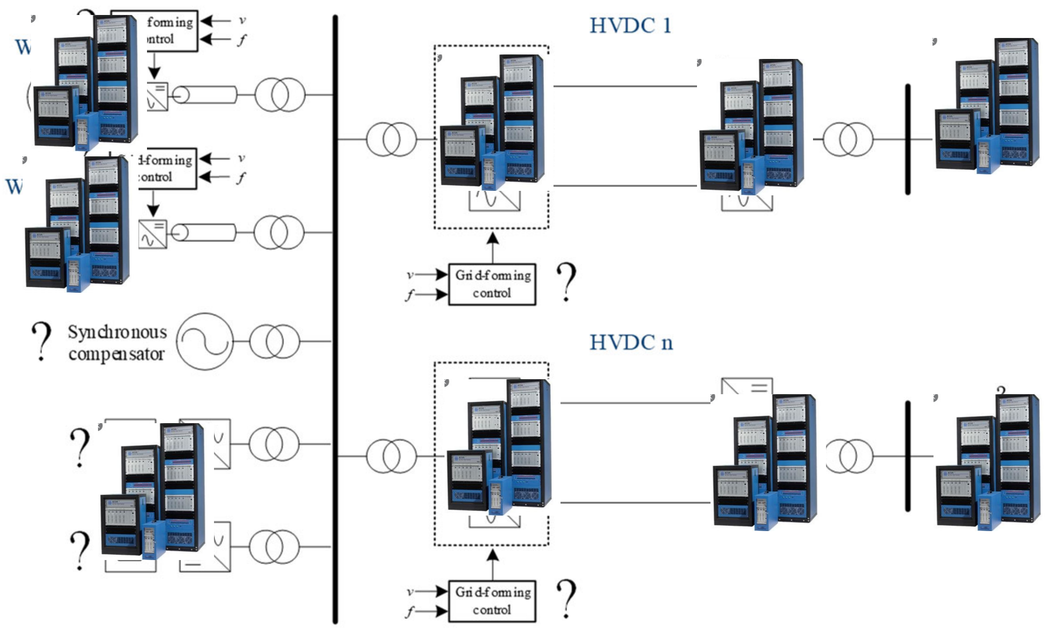
- The EMT model must represent all components, control systems and protection systems relevant for EMT analyses.
- All relevant function settings in the generation facility's control system that are relevant for EMT analyses and that can be changed either locally or remotely must appear as available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

ENERGINET

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