WELCOME

TECHNICAL MARKET DIALOGUE

ENERGY ISLAND BORNHOLM

6. OCTOBER

BORNHOLM ENERGY ISLAND

Bornholm Energy Island is one of the world's first energy islands and one of the largest construction projects in Danish history

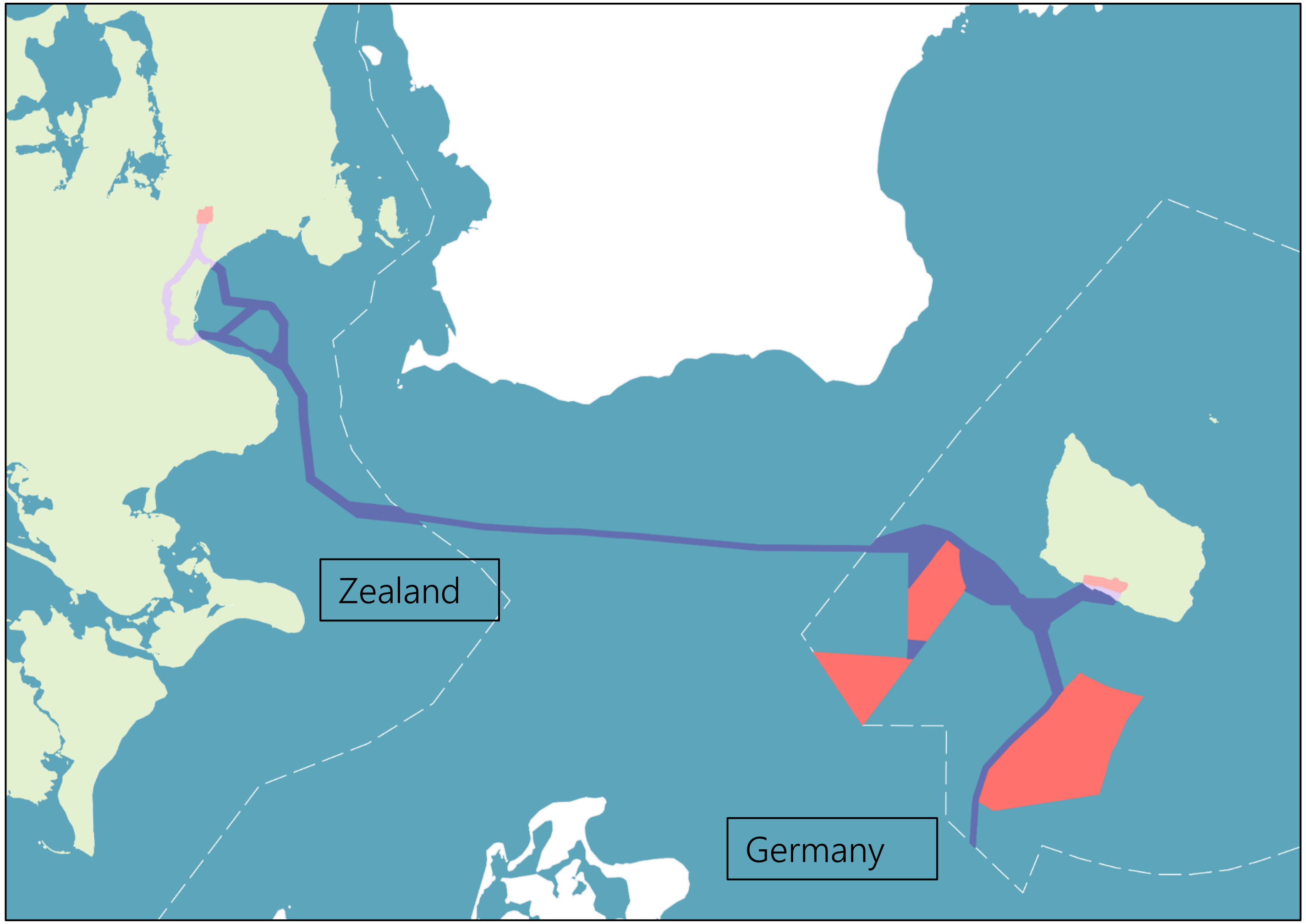
3 GW offshore wind with the option to overplant with 800 MW

Joint project with Germany

- 1,2 GW to Zealand
- 2 GW to Germany

45 km to 15 km near the shoreline of Bornholm

Technical dialogue regarding new innovative requirements which we are here to discuss with you



AGENDA

For the technical session

Introduction	10:10-10:25
Legislative basis	10:25-10:55
Break	10:55-11:05
System design and needs	11:05-11:50
Break	11:50-12:00
Compliance process	12:00-12:45
Lunch break	12:45-13:15
Technical requirements	13:15-14:00
Plenum and bilateral Q&A	14:00-14:50
End of the day and further process	14:50-15:00

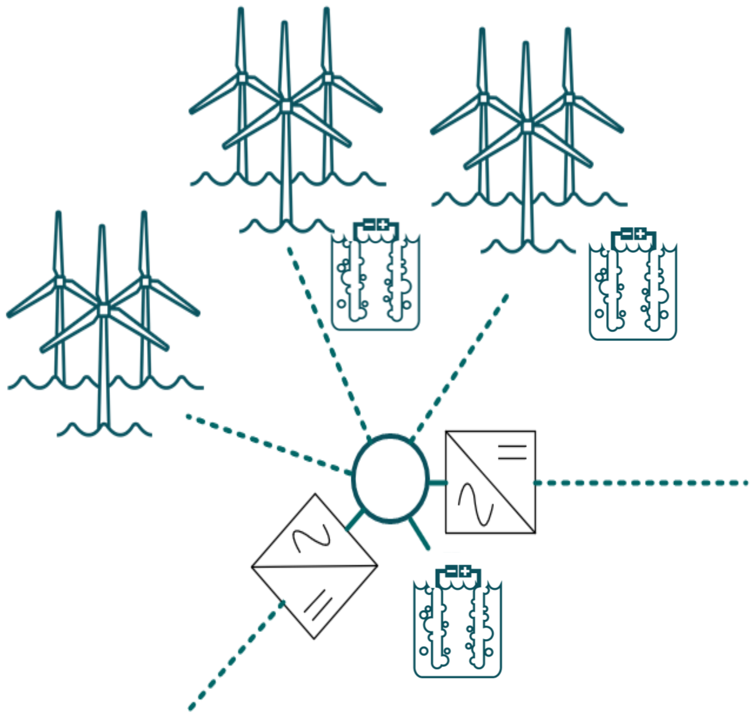
ENERGINET

INTRODUCTION

Motivation of a new technical framework

Bornholm Energy Island is a new type of highly complex power system where:

- It is an expandable multi-user system.
- All facilities are interfaced using power electronics.
- Each individual facility can strongly affect the technical performance of the power system on the energy island (extreme weak grid).
- Overplanting and co-location is introduced.



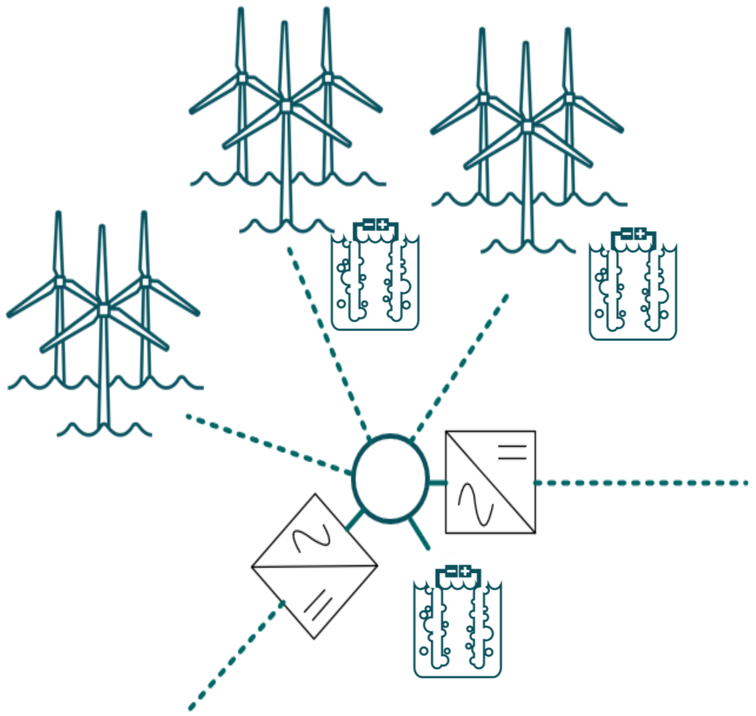
INTRODUCTION

Motivation of a new technical framework

Because of the system characteristics:

- Adjustment of existing and introduction of new performance requirements is needed.
- Enhanced analysis and simulation capabilities are needed to increase predictability and hence allow sufficient de-risking for all actors in all project stages.
- A higher than usual need for coordination and corporation between actors is needed – this while respecting IPR.

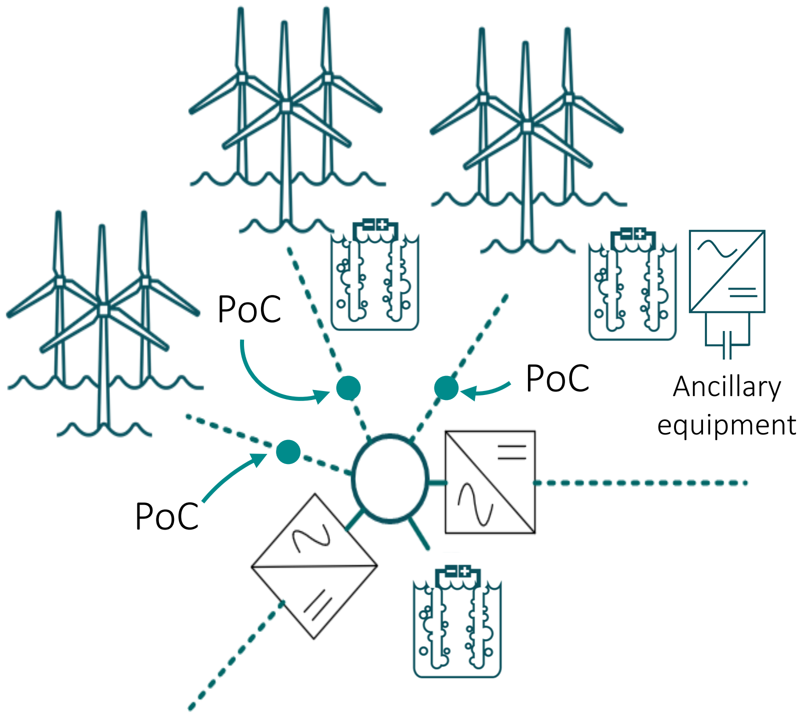
To facilitate secure grid integration for Energy Island type of systems, a new technical framework is under development.



INTRODUCTION

Philosophy underlying the technical framework

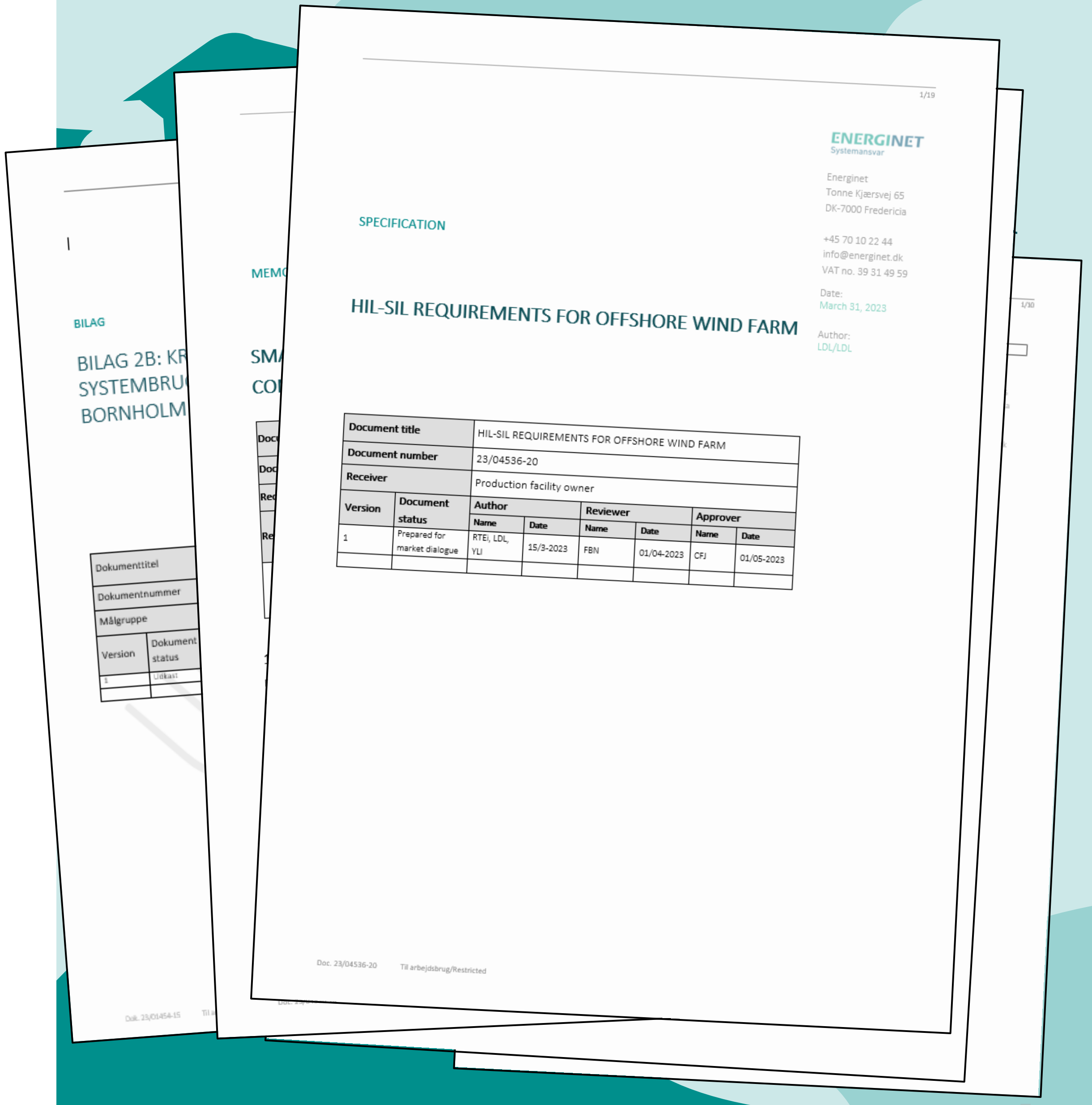
- The technical requirements are, to the highest degree possible, set at the PoC with a basis in the exchange capacity.
- Developers are, to the highest degree possible, allowed to ensure PoC-performance using any individual facility as well as any type of ancillary equipment.
- It is the sole responsibility of the developer to devise a design that fulfills all technical requirements.



INTRODUCTION

Before the final publication

- The technical framework is described in seven publications.
- Still, more interactions between TSO and developer are necessary to ensure sufficient understanding on both sides.
- Provide your inputs and help us improve the material.

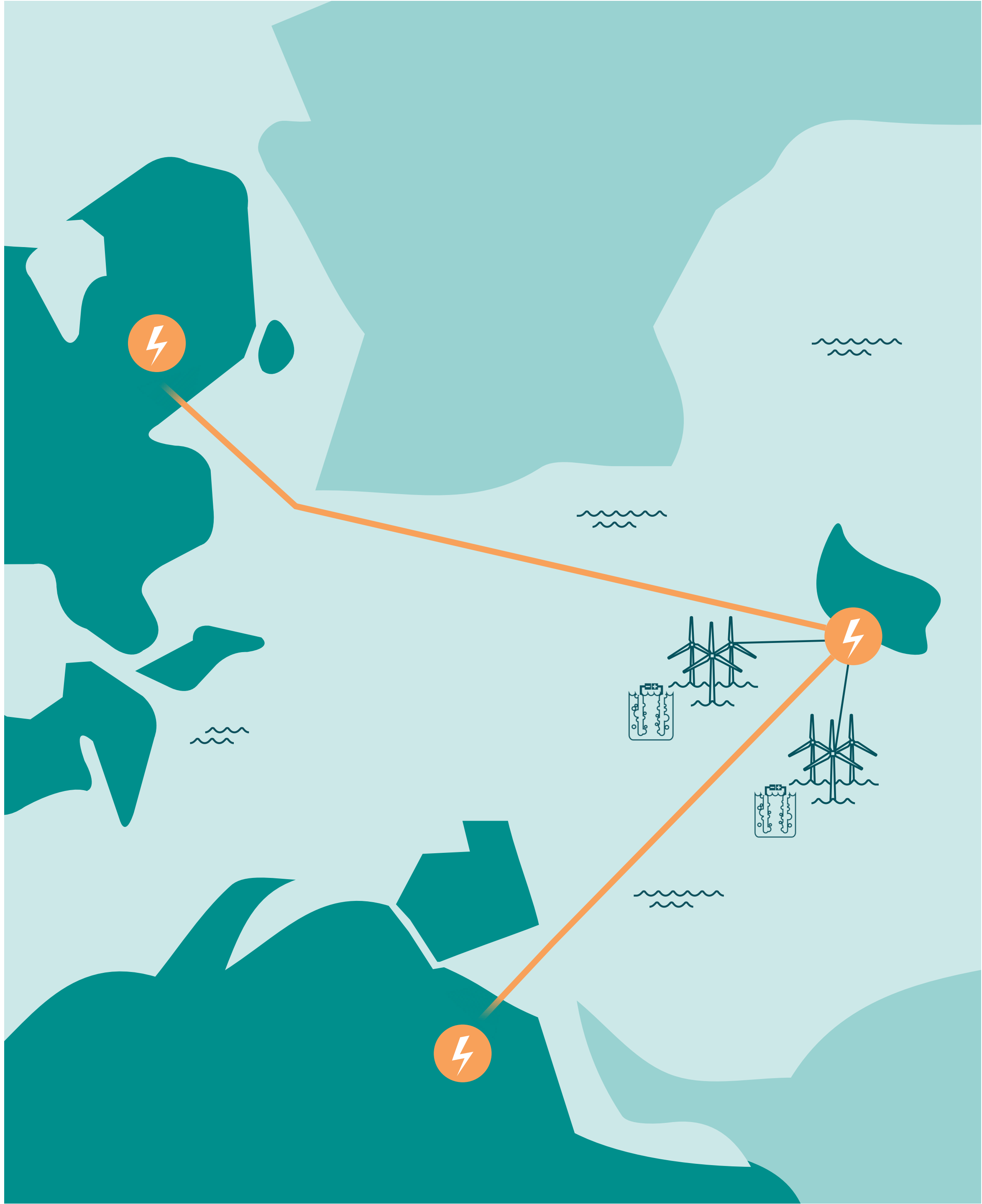


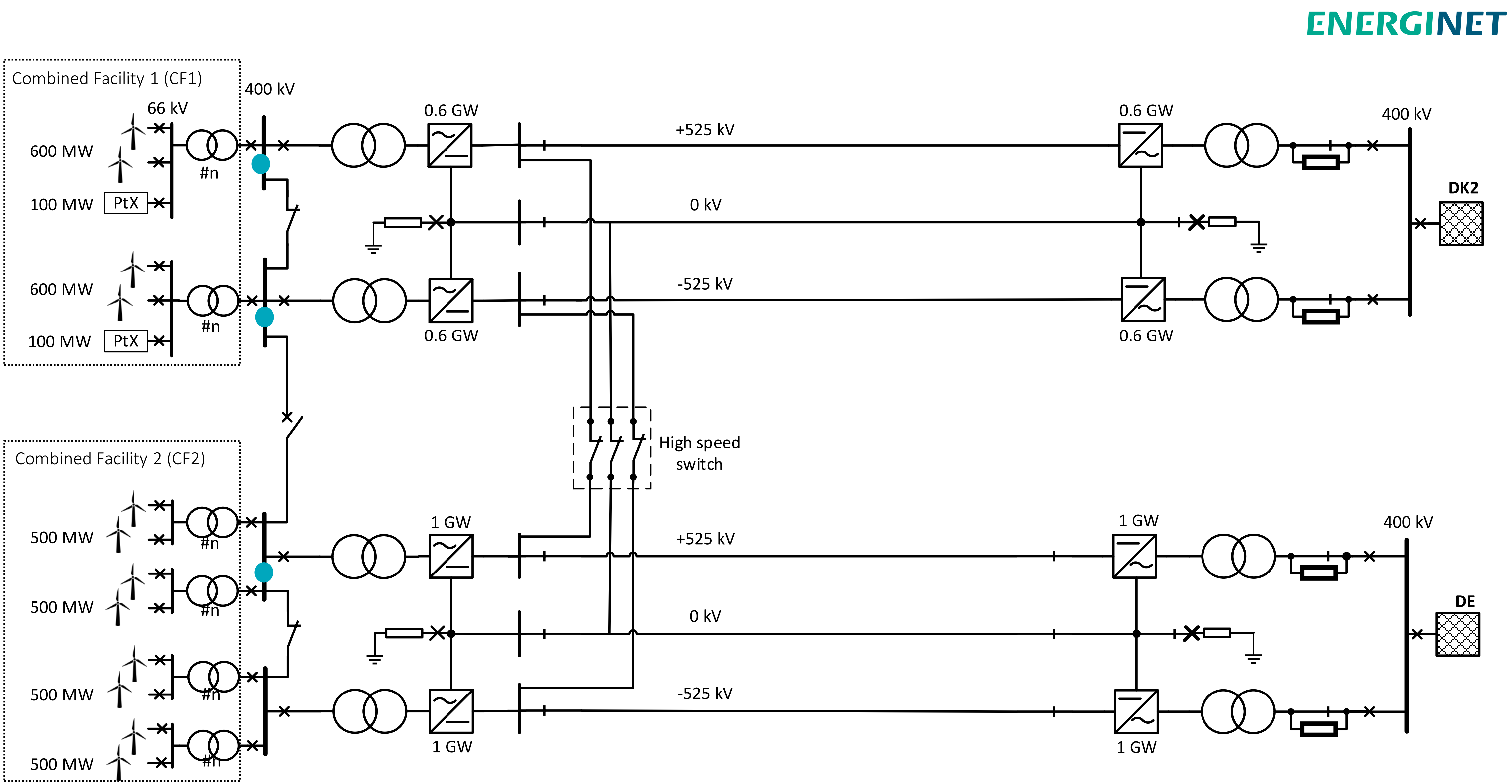
INTRODUCTION

High level description of Bornholm Energy Island’s electrical infrastructure

First stage system description.

- Two combined facilities
  - 1 GW + 0.2 GW_{op} wind and 0.2 GW demand.
  - 2 GW + 0.6 GW_{op} wind and 0.6 GW demand.
- Two HVDC-based inter-connectors
  - 1.2 GW between Denmark (DK2) and Bornholm Energy Island (BEI) .
  - 2.0 GW between BEI to Germany (DE, 50 HertZ).
- The Bornholm distribution system.





CF1: wind power plant of 1 GW+ 0.2 GW overplanting and potential 0.2 GW demand.
CF2: wind power plant of 2 GW+ 0.6 GW overplanting and potential 0.6 GW demand.

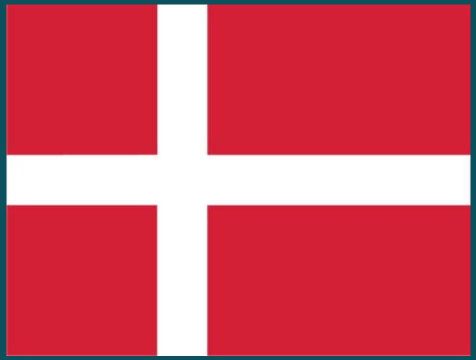
The blue dots indicate the connection of the 400/132 kV transformers to the Bornholm distribution system

LEGISLATIVE BASIS AND CONNECTION REQUIREMENTS

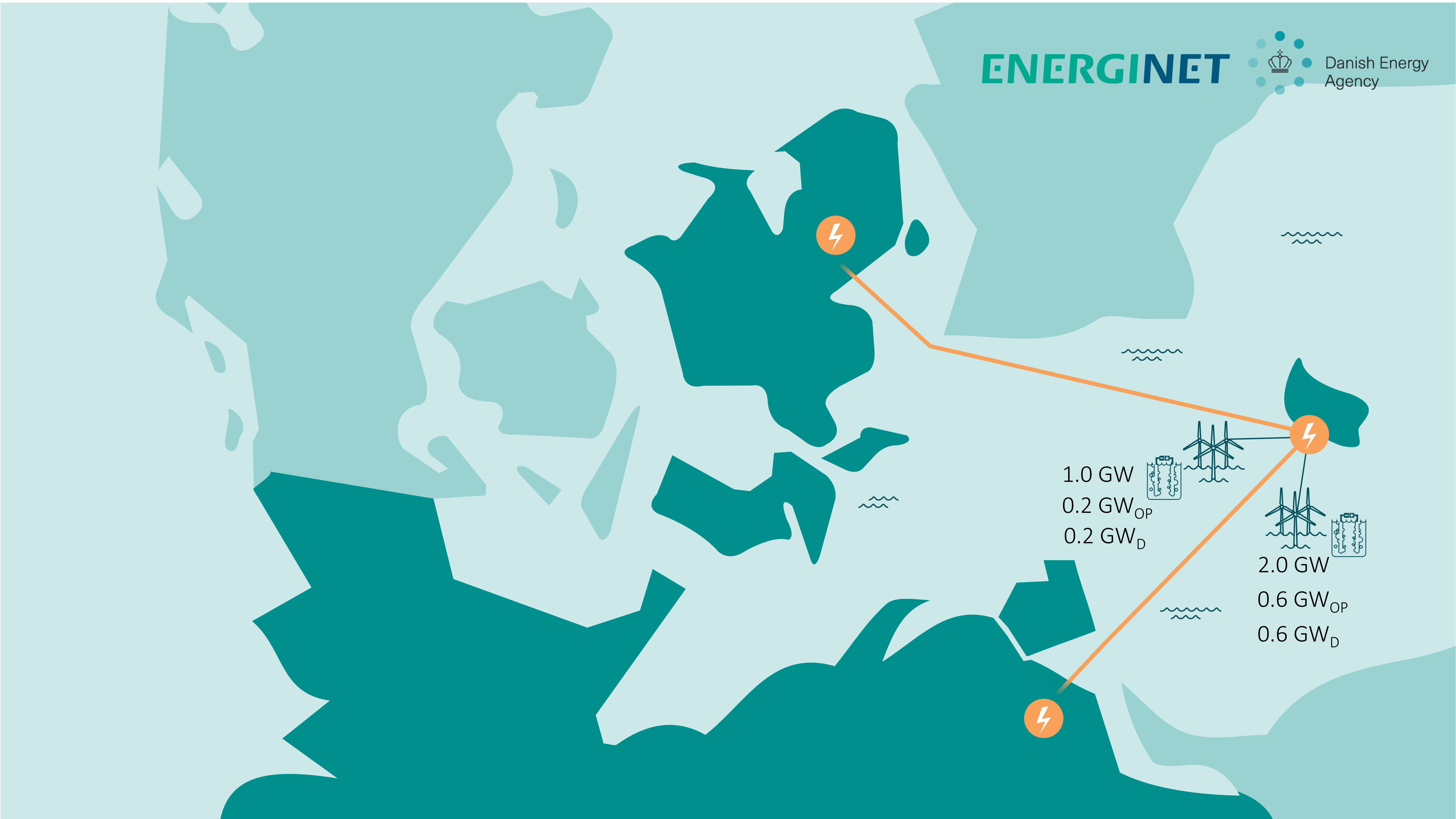
Flemming Brinch Nielsen

BEI and 3 GW OWF CONNECTION REQUIREMENTS

Slide 1/18



- Legislative basis – grid connection
- New terms
- Applicability of requirements
- New national requirements
- New European requirements
- Stakeholder interaction
- Operation Notification Process
- Successive connection and mutual dependencies
- Summary

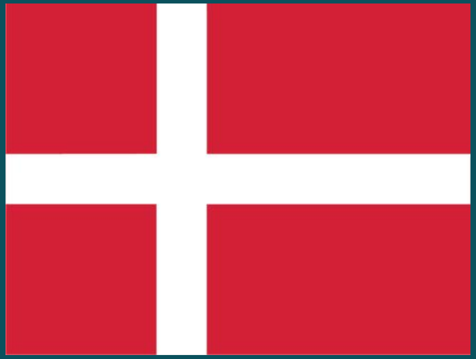

ENERGINET
Danish Energy Agency
1.0 GW
0.2 GW$_{OP}$
0.2 GW$_{D}$
2.0 GW
0.6 GW$_{OP}$
0.6 GW$_{D}$

GRID CONNECTION - LEGISLATIVE BASIS

Requirements for grid connection

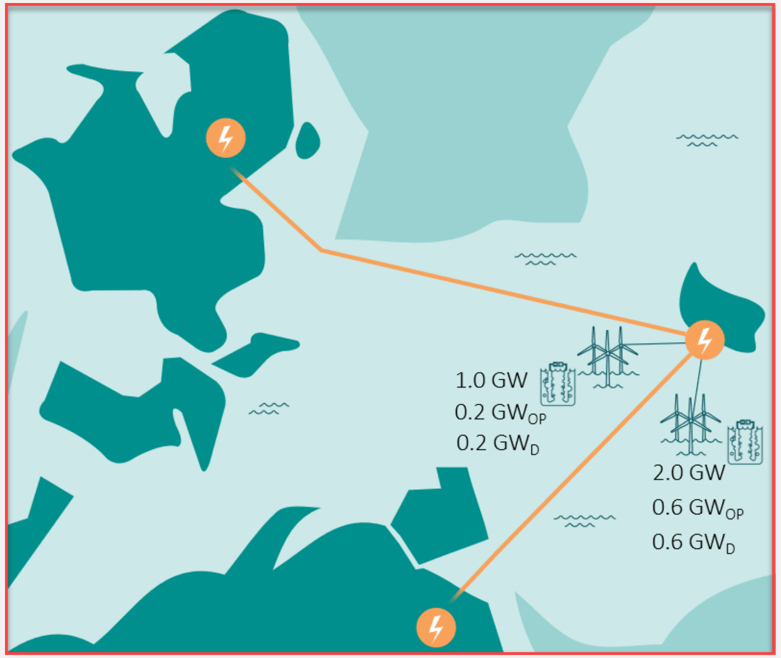
BEI and OWF

Slide 3/18



BEI and 3 GW OWF

- Commission Regulation (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules
- Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators

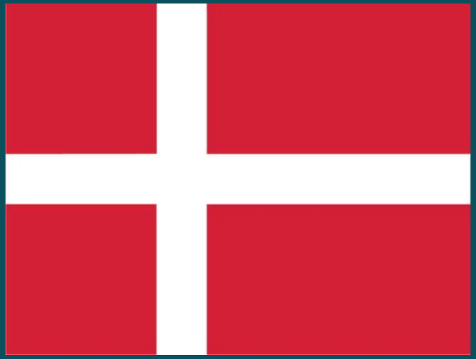


GRID CONNECTION - LEGISLATIVE BASIS

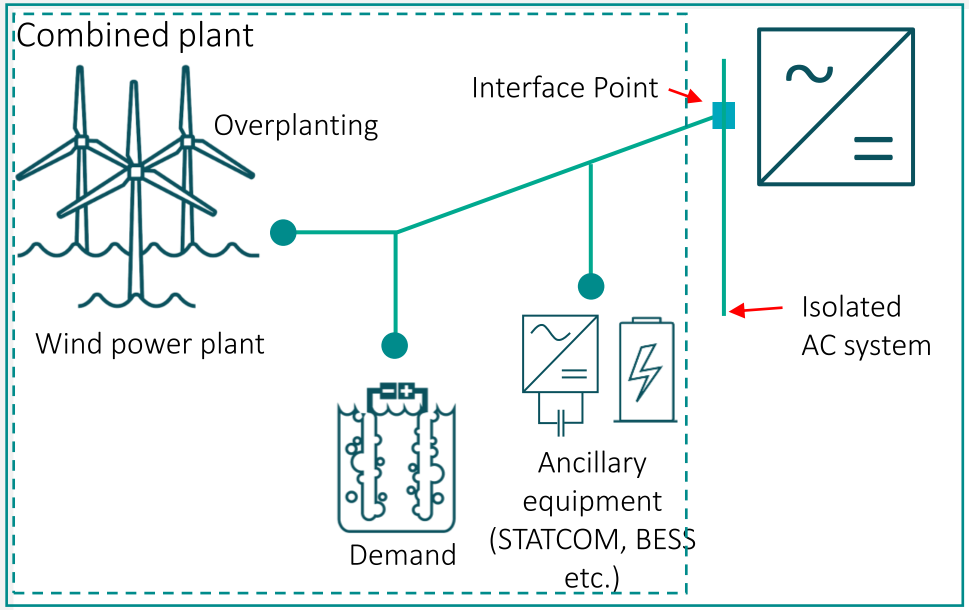
Requirements for grid connection

BEI and OWF

Slide 4/18



BEI and 3 GW OWF

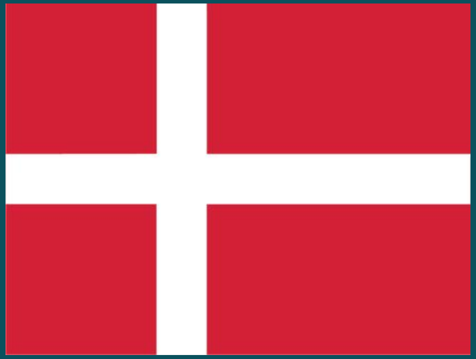


- Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network code on Demand Connection
- Relevant national technical regulations
- New developed connection requirements
- Connection Agreement
- Connection requirements applicability
  - Not a negotiation proposal however a constructive dialogue is needed for creating the best solution

GRID CONNECTION - LEGISLATIVE BASIS

Requirements for grid connection

Slide 5/18



Scope for requirement work – a Energinet task

- How does “the new connections” fit into existing regulation and what needs to be done?

- Update 2016/1447 requirements
  - DC connected PPM
  - Remote-end HVDC converter station
- Application for derogation to existing requirement
- New TR requirements for co-location and overplanting
- New regulation requirements addressing overplanting
- New regulation requirements addressing co-location
- Already submitted requirements awaiting approval from NRA ((EU)2016/631 & (EU)2016/1388)

ENERGINET

NEW TERMS IN REQUIREMENTS

Definition of Overplanting
Slide 6/18

- Overplanting: When the installed generation capacity, $P_{install}$, is greater than P_{max}, the agreed active power of the connection agreement, which is exchanged with the collective electricity supply system.
- ($P_{install} \neq P_{max}$@NTA)

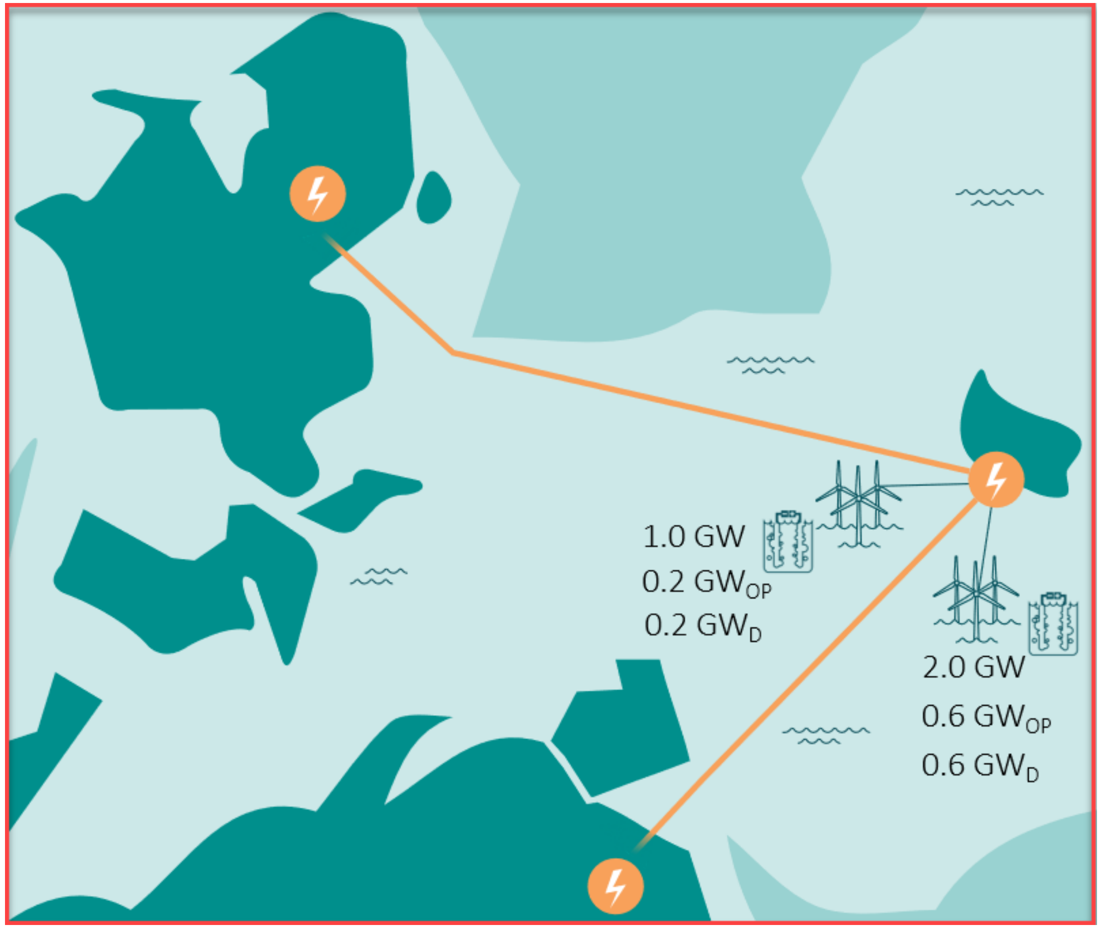
Overplanting - in three variations

- Apply basic connection requirements
  - Not relevant at BEI
- Optimize generation profile
  - Includes spare WTG for service
  - Change generation profile
  - Not relevant at BEI
- Install additional generation capacity to supply of self-consumption

NEW TERMS IN REQUIREMENTS

Overplanting, Demand and Connection agreement Slide 7/18

- Overplanting (OP) (in total)
  - 0.2 GW + 0.6 GW = 0.8 GW
- Demand facility (D)(in total)
  - 0.2 GW + 0.6 GW = 0.8 GW
- Connection Agreement
  - 1.0 GW + 2.0 GW = 3.0 GW (fixed generation)
  - Demand permit no/low wind scenario(?)

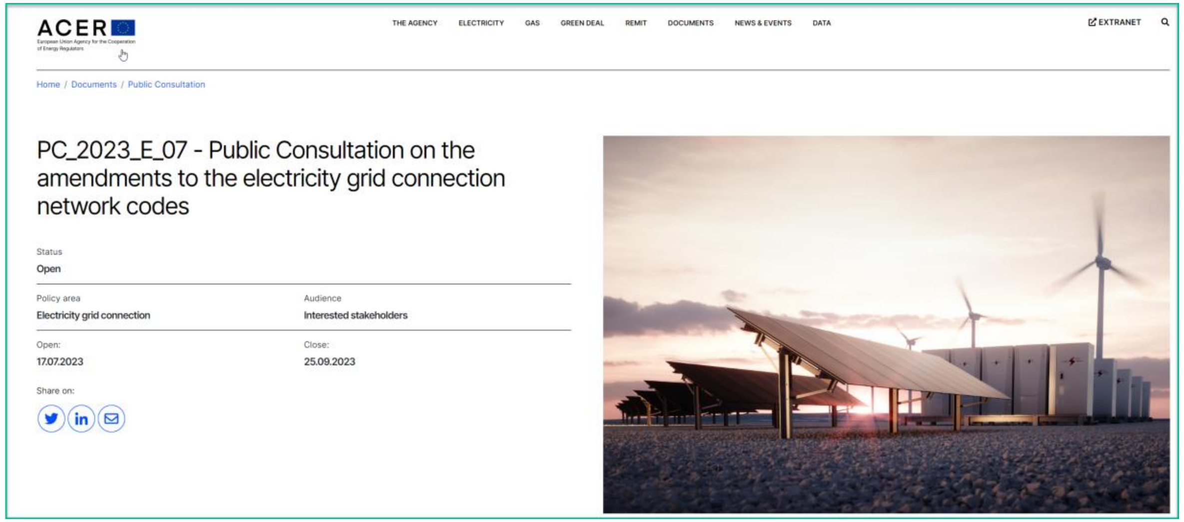


ENERGINET

NEW EUROPEAN REQUIREMENTS

Amendments of NC RfG and NC DC
Slide 8/18

- Process facilitated by ACER
- Public consultation ended 25 September 2023
- Expected final proposal ready, Q4 2023
- Submission to EC, Q4 2023
- Final process – unknown so far
- Entering into force - unknown so far



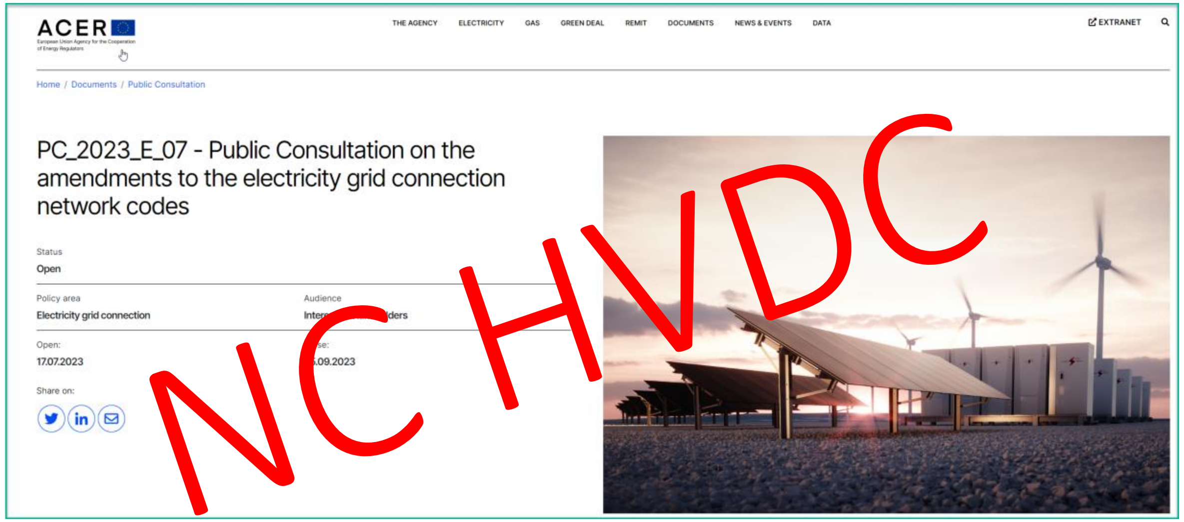
- Regulatory changes will affect facility design and connection requirements

ENERGINET

NEW EUROPEAN REQUIREMENTS

Amendments of NC HVDC
Slide 9/18

- Process facilitated by ACER
- Process started in 2024
- Expected final proposal ready, Qx 2024
- Expected finalized in 2024, Qx 2024
- Final process – unknown so far
- Entering into force - unknown so far



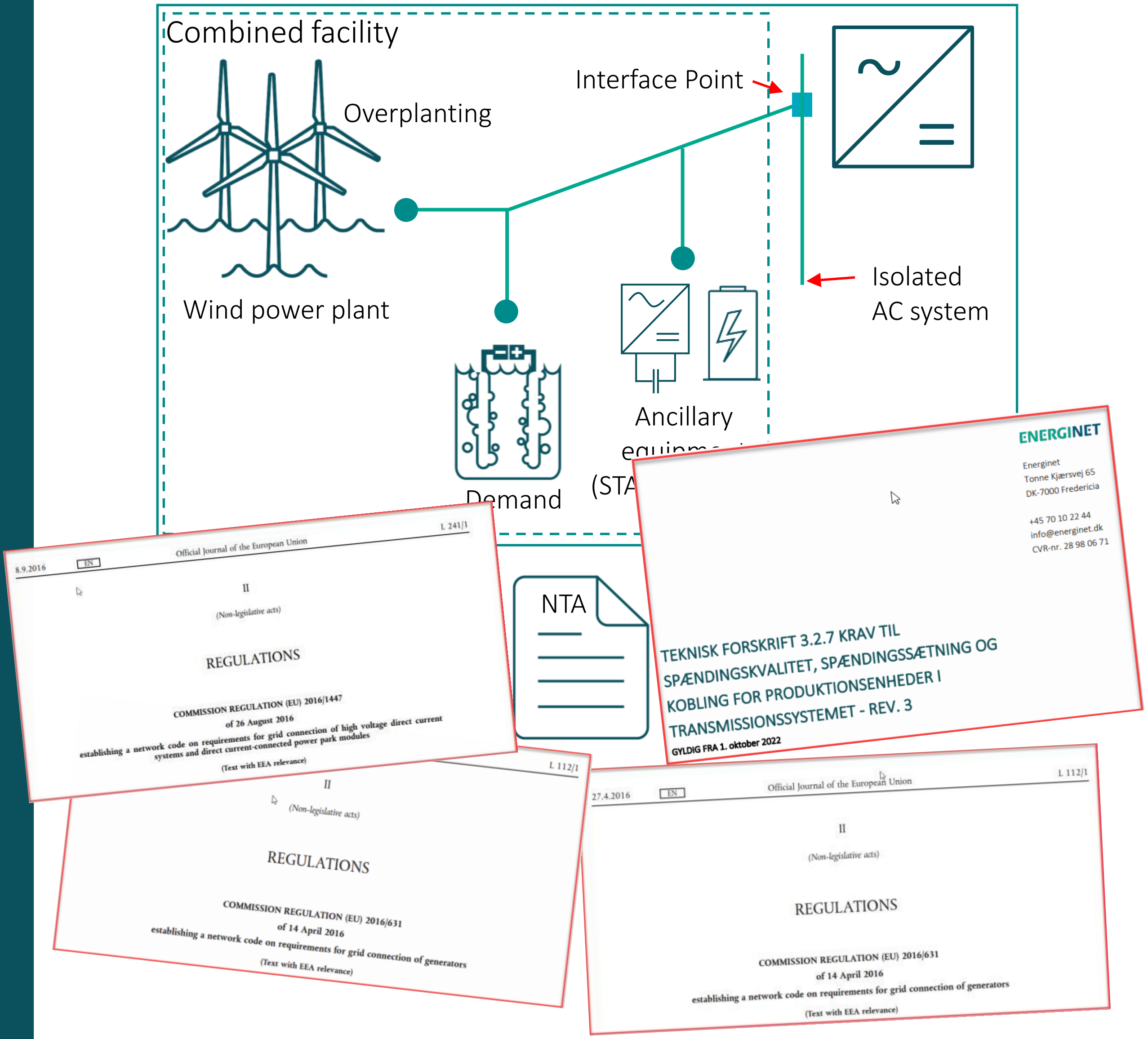
- Regulatory changes will affect facility design and connection requirements

ENERGINET

LEGISLATIVE BASIS - GRID CONNECTION

Requirements for grid connection, Slide 10/18

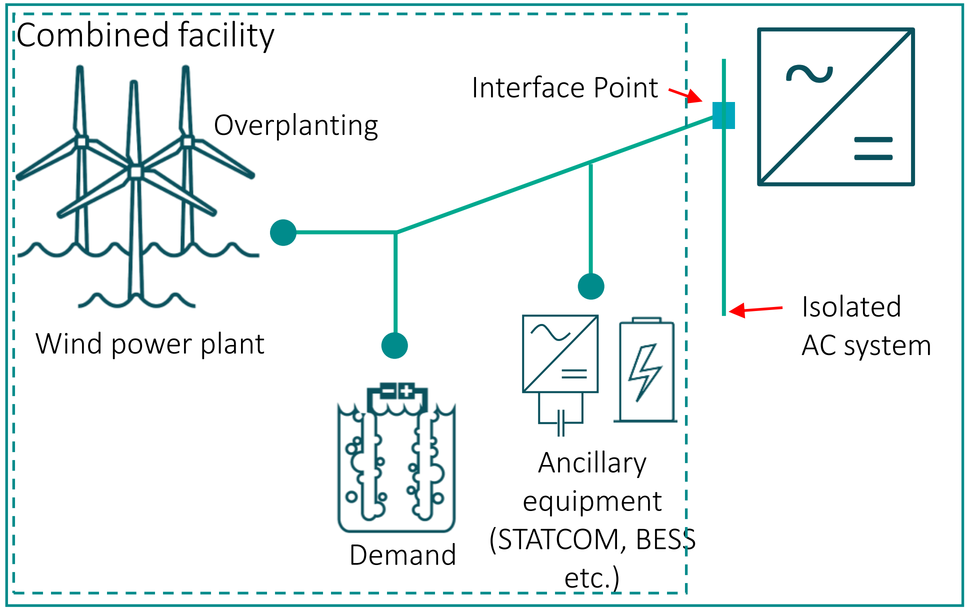
- Requirements applicable for
  - The entire facility (generation, overplanted, demand etc.)
  - At Interface point, (Isolated AC system) when no other option is mentioned
  - Where PPM are mentioned, the term should be - DC connected PPM
- The process for finalizing requirements starts now

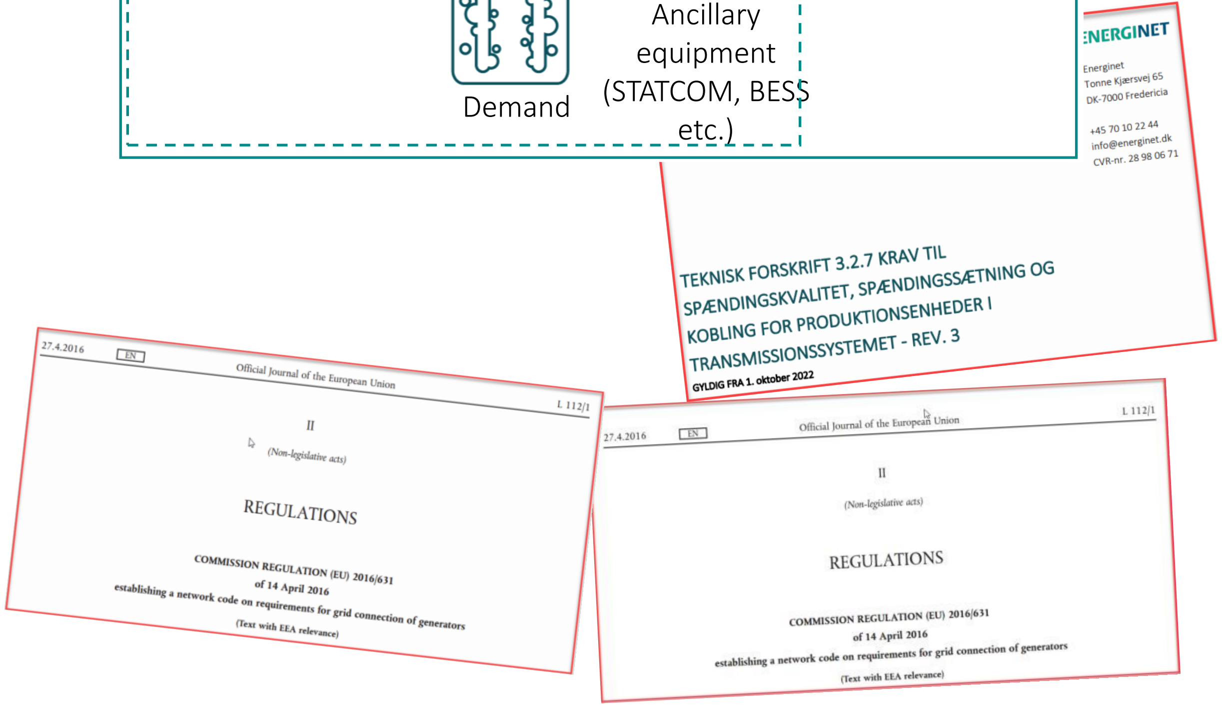


PUBLIC MEETINGS FOR REQUIREMENTS

Stakeholder interaction, slide 11/18

- Energinet will facilitate public meetings where;
  - Requirements/details are presented
  - Stakeholder can provide feedback
  - Meeting format not decided yet
  - Plan for meetings will be public





ENERGINET

CONNECTION REQUIREMENTS

Operation Notification Procedure
Slide 12/18

- Standard procedure
- New procedure needs to be developed
  - Successive connection

- EU 2016/1447
- HVDC systems, Article 55 – 59
- DC PPM, Article 60 - 64

  - Energization Operational Notification (EON)
  - Interim Operational Notification (ION)
  - Final Operational Notification (FON)
  - (Limited Operational Notification (LON))

- Planning of ION
  - When concession winner is known
  - When OWPP is known in needed details

ENERGINET

CONNECTION REQUIREMENTS

Operation Notification Procedure
Slide 13/18

- Energization Operational Notification (EON)
- Interim Operational Notification (ION)
- Final Operational Notification (FON)

EON

- Energize internal network and auxiliaries
- Completed preparations (protection, control settings, documentation on passive components, etc.)

ION

- Operate the facility, generate power
- Subject to completion of the data and study review process (facility)
- Maximum duration of 24 months

FON

- Operate the facility
- upon prior removal of all incompatibilities identified during ION and subject to completion of the data and study review
- Derogation option

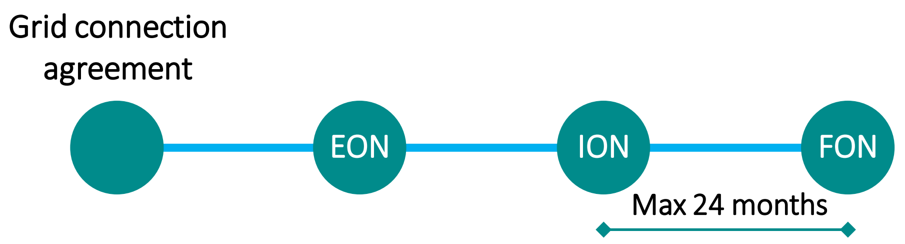
CONNECTION REQUIREMENTS

Operation Notification Procedure
Slide 14/18

- New procedure needs to be developed
  - Successive connection of the generation facility

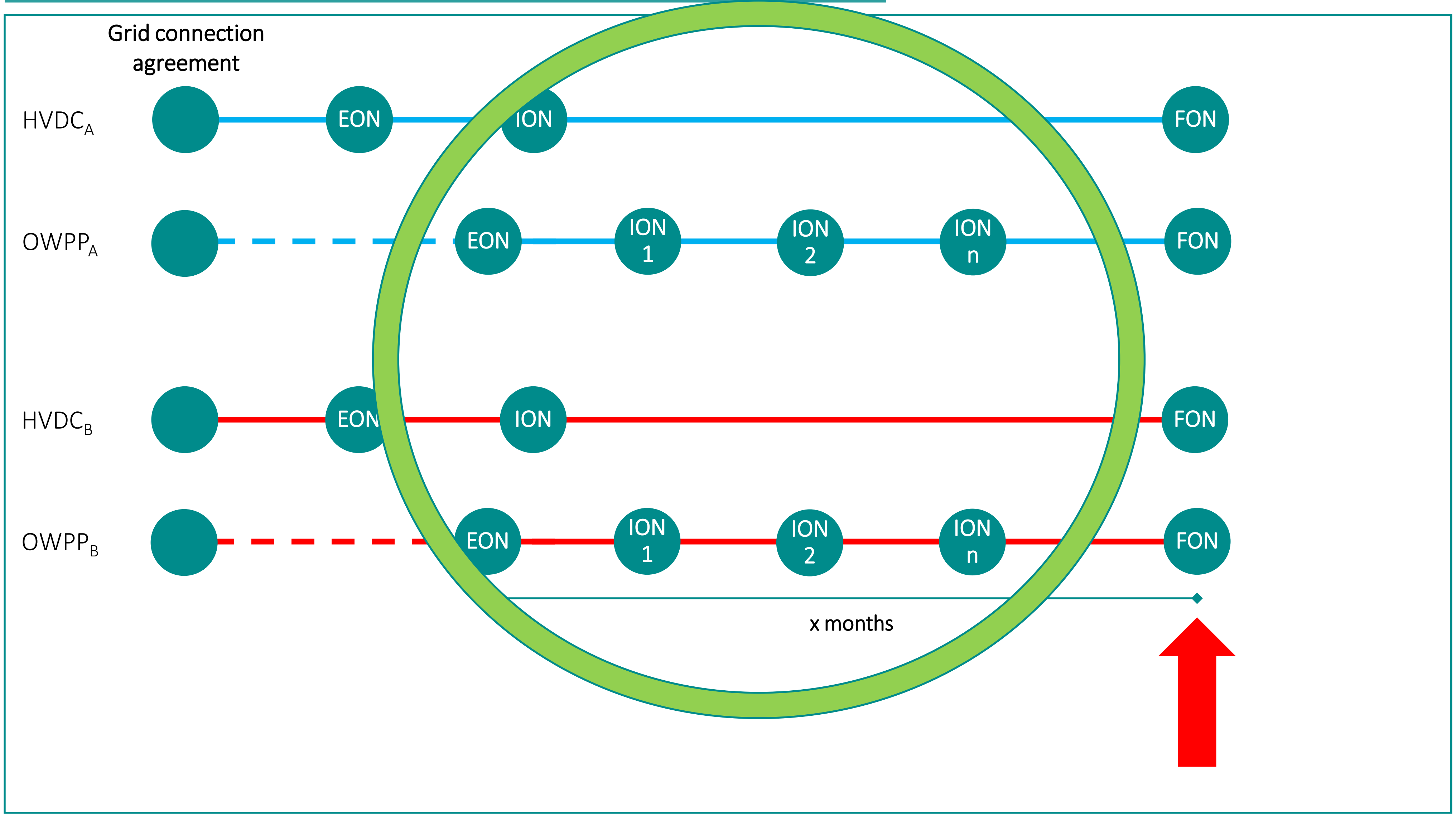
- Energinet will develop a new ONP
  - Focus ION
  - Apply derogation for the existing
  - Try to accommodate stakeholder need
  - Ensure the system and RSO need during the connection process

Normal perception of the current ONP



OPERATION NOTIFICATION PROCEDURE

Example of timeline for possible successive connection and coordinated test connections



The timing of EON for OWF is assumed relative to this example.

The timing and numbers of successive ION for OWF is assumed relative to this example.

OPERATION NOTIFICATION PROCEDURE

Example of timeline for possible successive connection and coordinated test connections

The ION tests all applicable configurations

$HVDC_A$ ION

$OWPP_A$ ION

$HVDC_B$ ION

$OWPP_B$ ION

	HVDC-A	OWPP-A	OWPP-B	HVDC-B
HVDC-A	n/a	x	x	x
OWPP-A	x	n/a	x	x
OWPP-B	x	x	n/a	x
HVDC-B	x	x	x	n/a

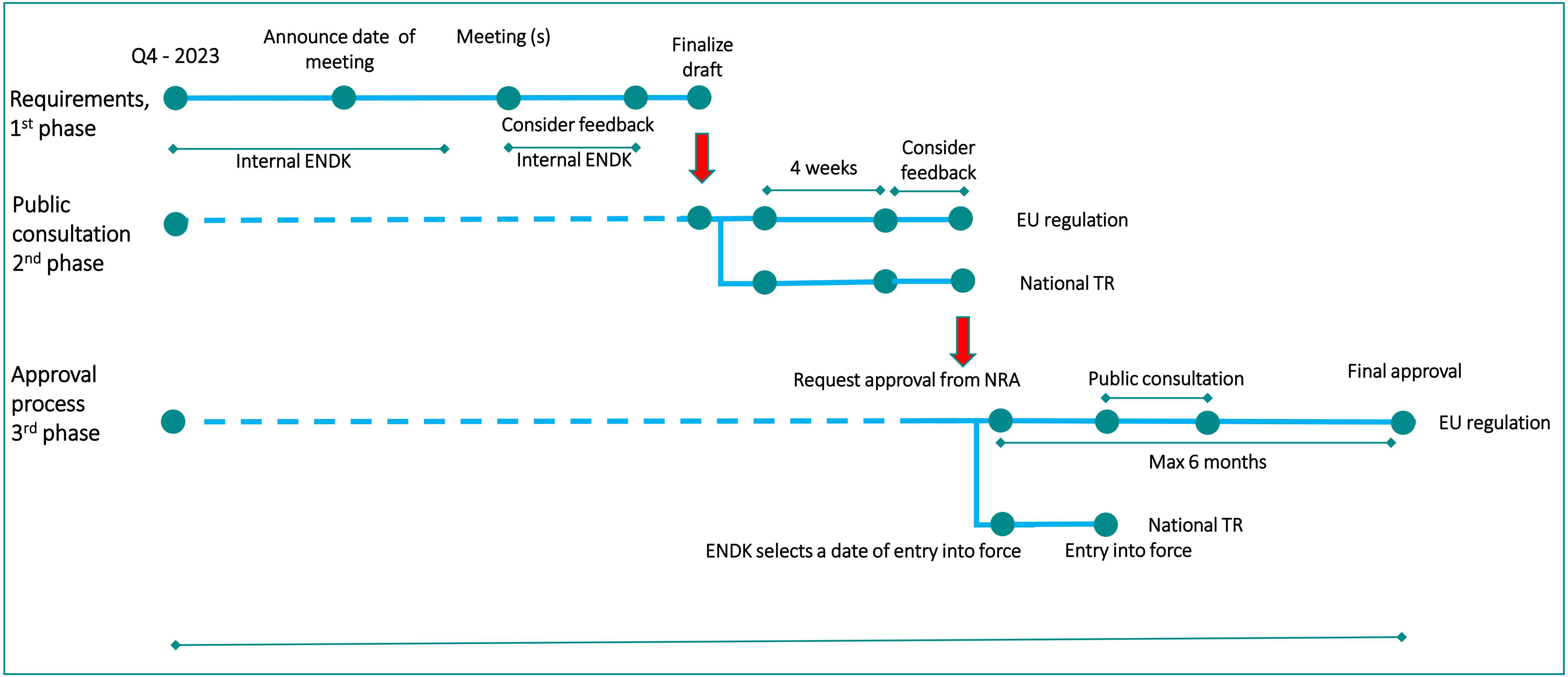
FON

FON

FON

FON

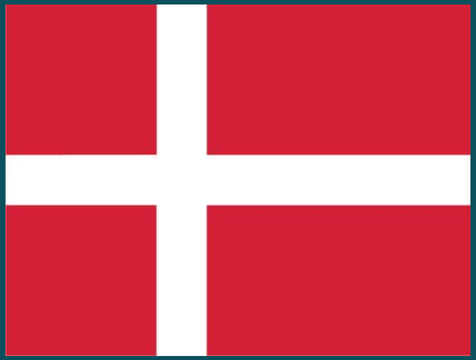
REQUIREMENT DEVELOPMENT AND APPROVAL PROCESS



GRID CONNECTION - LEGISLATIVE BASIS

Requirements for grid connection

Slide 18/18



Summary

- Requirements are applicable for the combined facility at the interface point of the isolated AC-system
- The process for finalizing requirements starts now – pay attention, get involved
- The process is facilitated by Energinet
- Requirements will consist of EU regulation and national TR
- Significant changes of the facility will delay the entire project
- Pay attention to the coming changes in EU regulation

PAUSE

SYSTEM DESIGN AND NEEDS

Adrian Expethit

Power System Design

SYSTEM DESIGN AND NEEDS

Introduction

- From experience the term "Energy Islands" can have various interpretations, here we outline functionality of Bornholm Energy Island
- The aim of this walk-through is to communicate the special needs of the Bornholm Energy Island System
- The walk-through of the system is presented for everybody to have a common basis for the technical discussions later

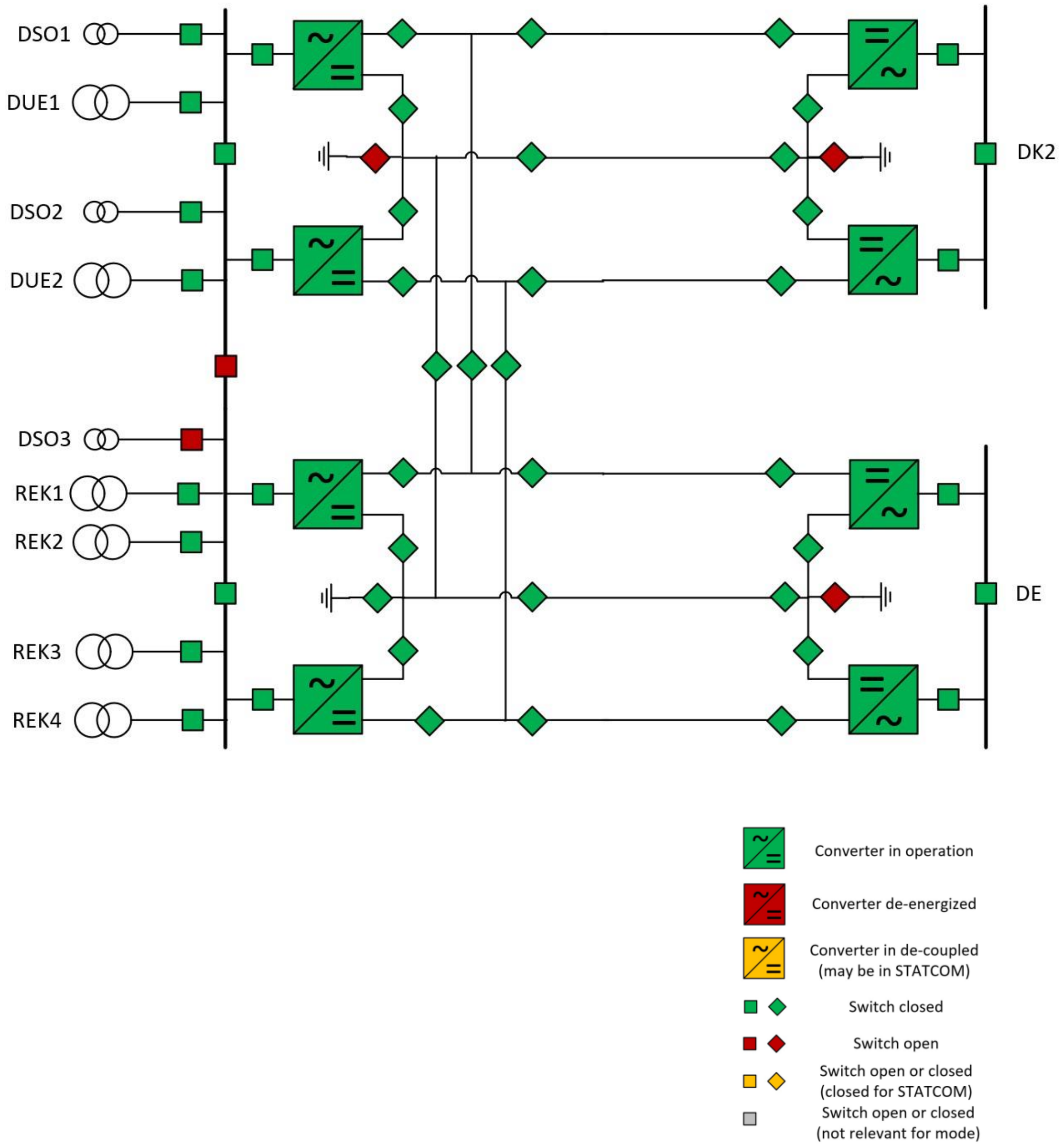
OVERVIEW OF SYSTEM TOPOLOGY

Highlighting relevant content of system

- 3x132 kV (or lower) to Bornholm Distribution system
- DC coupled HVDC system
  - No DC breaker in the DC coupling – non-selective scheme
- DC choppers at DK2 and DE side
- Coordinated Energy Island System Control

The system does NOT contain:

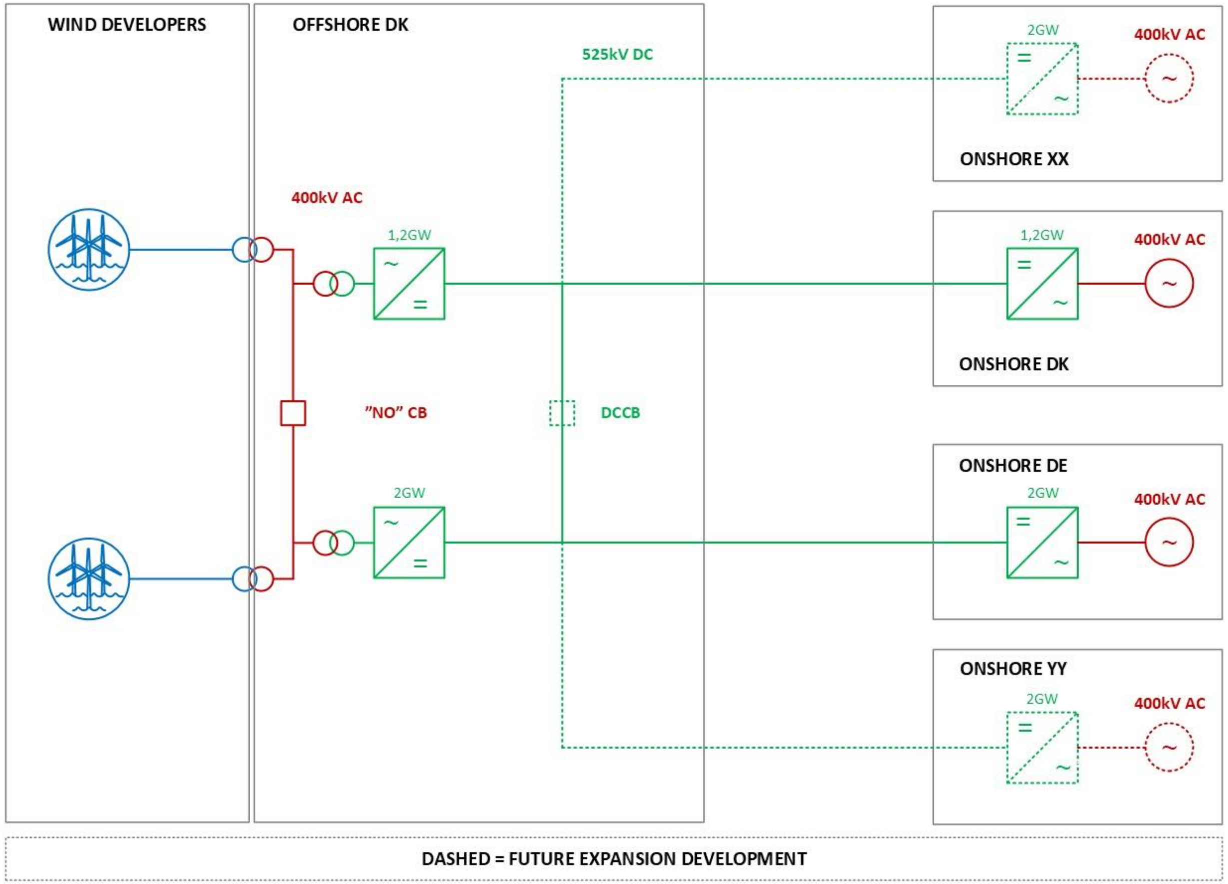
- Connection to Sweden



OVERVIEW OF SYSTEM TOPOLOGY

Expansion of the system

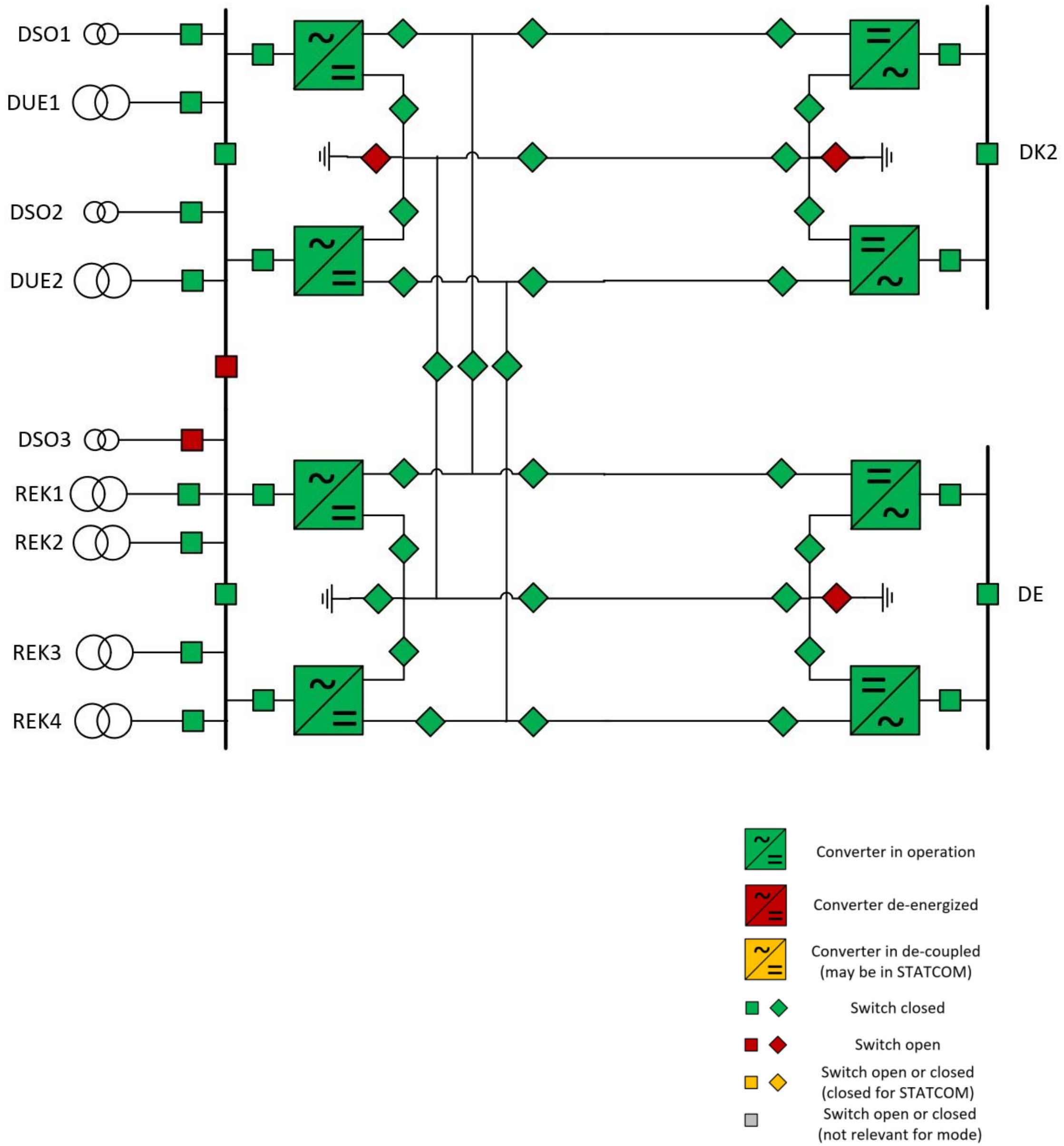
- Up to two additional 2x1 GW HVDC bipole links connected to the DC switching Station
- Addition of DC breakers to separate the DC switching station on Bornholm
- Any connection of generation or demand on the 400 kV Isolated system on Bornholm



OPERATION OF BEI

Coupling modes in Normal Operation

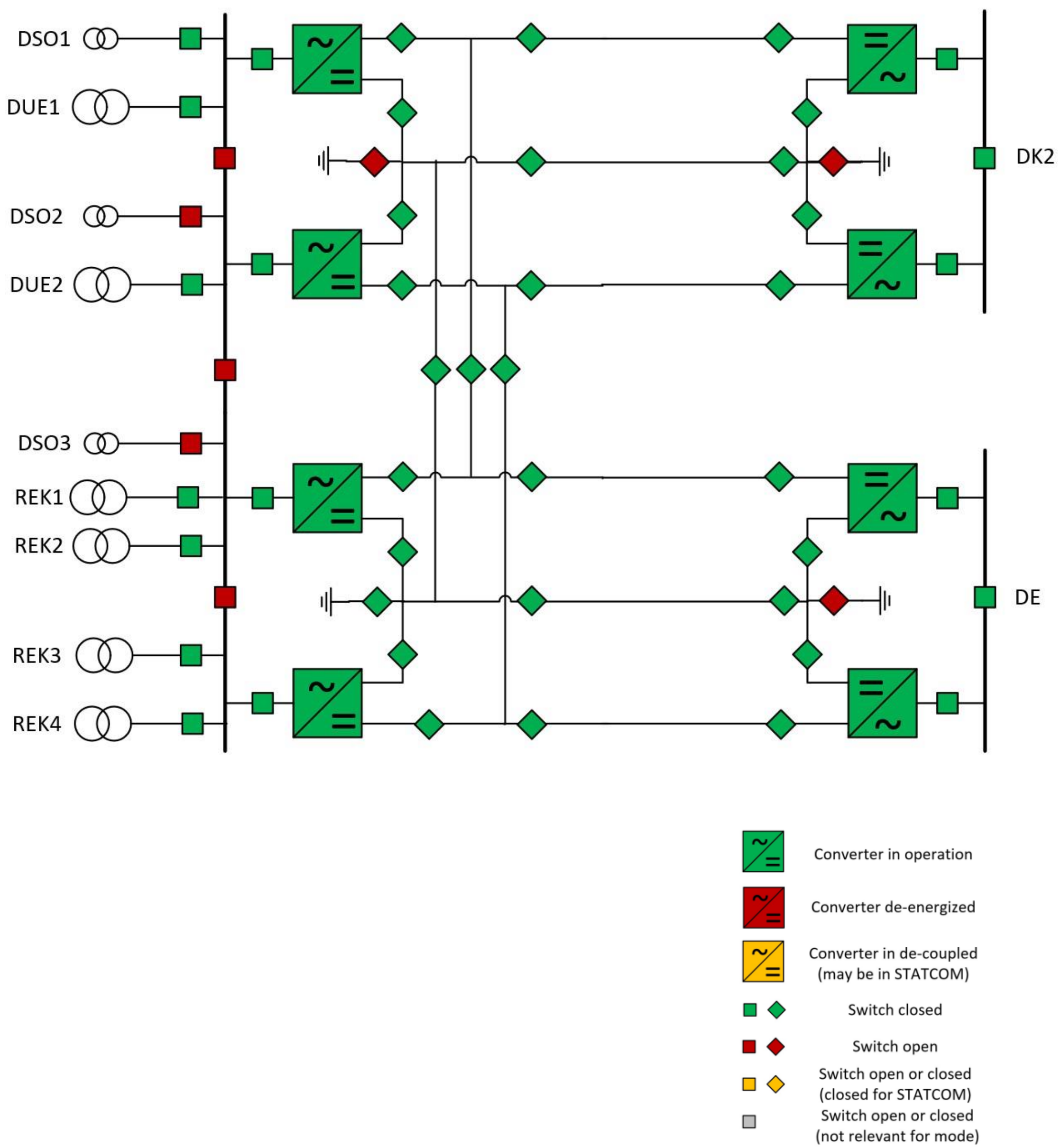
- In Normal Operation:
  - Combined facility 1 and 2 are coupled on the AC side
  - There will be access to both DK2 and DE bidding zones
  - Bornholm distribution system is only connected to the 1.2 GW bipole system



OPERATION OF BEI

Coupling modes in Normal Operation

- In Normal Operation:
  - Combined facility 1 and 2 are coupled on the AC side
  - There will be access to both DK2 and DE bidding zones
  - Bornholm distribution system is only connected to the 1.2 GW bipole system
- Operational limitations:
  - Can lead to disconnection of poles on the AC side
  - Can lead to disconnection of bipole system in the busbar

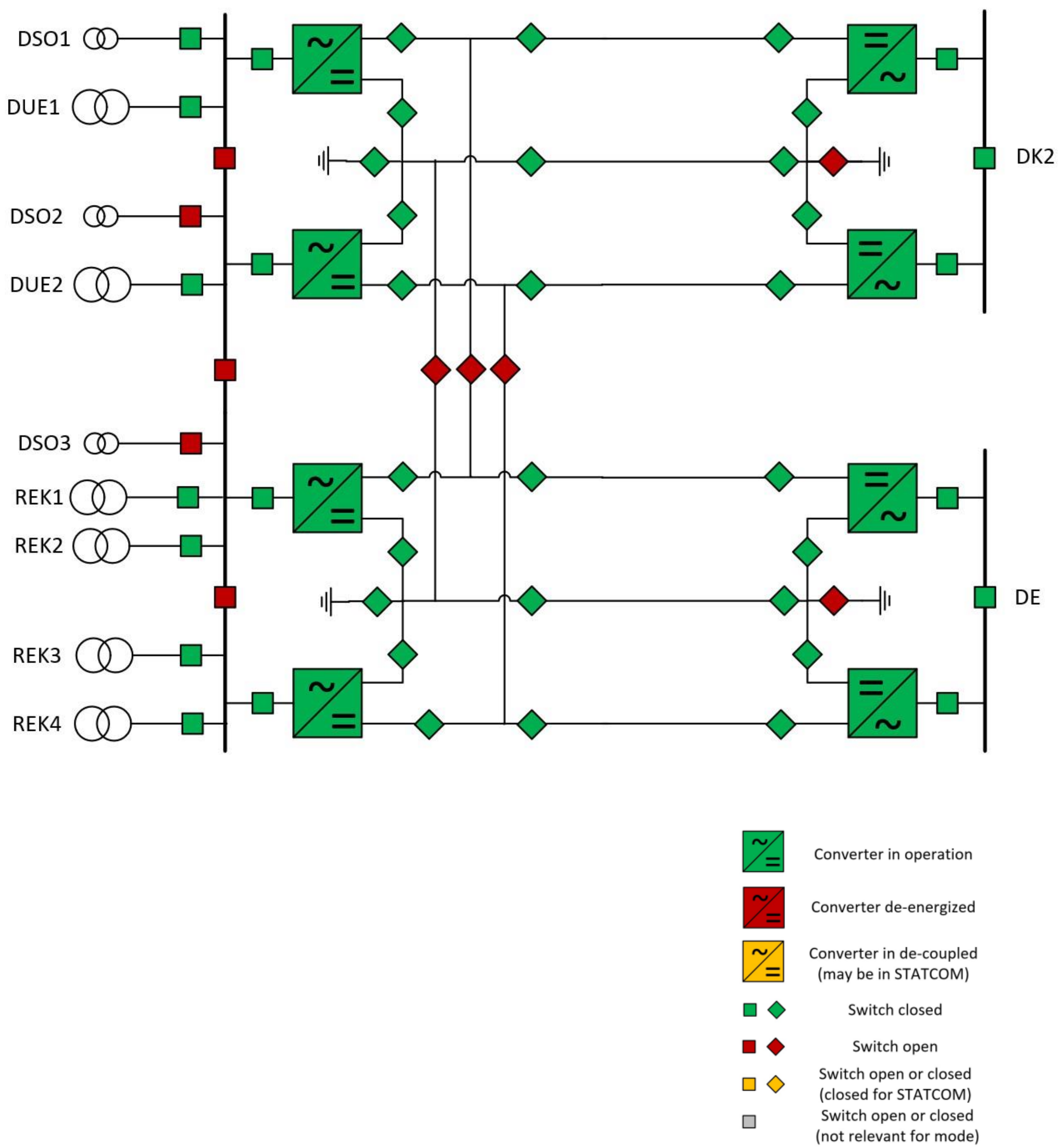


OPERATION OF BEI

Coupling modes in Normal Operation

- In Normal Operation:
  - Combined facility 1 and 2 are coupled on the AC side
  - There will be access to both DK2 and DE bidding zones
  - Bornholm distribution system is only connected to the 1.2 GW bipole system
- Operational limitations:
  - Can lead to disconnection of poles on the AC side
  - Can lead to disconnection of bipole system in the busbar

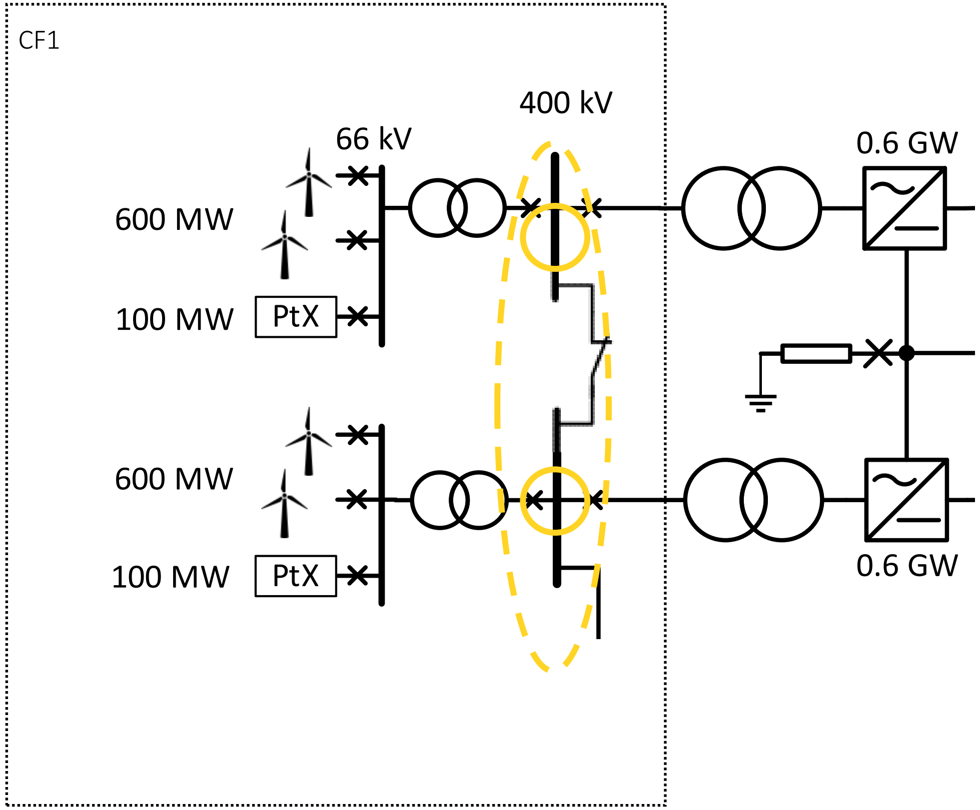
While both bipole systems are in operation, the AC coupling of both Combined facilities will never happen



OPERATION OF BEI

Coupling modes in Normal Operation

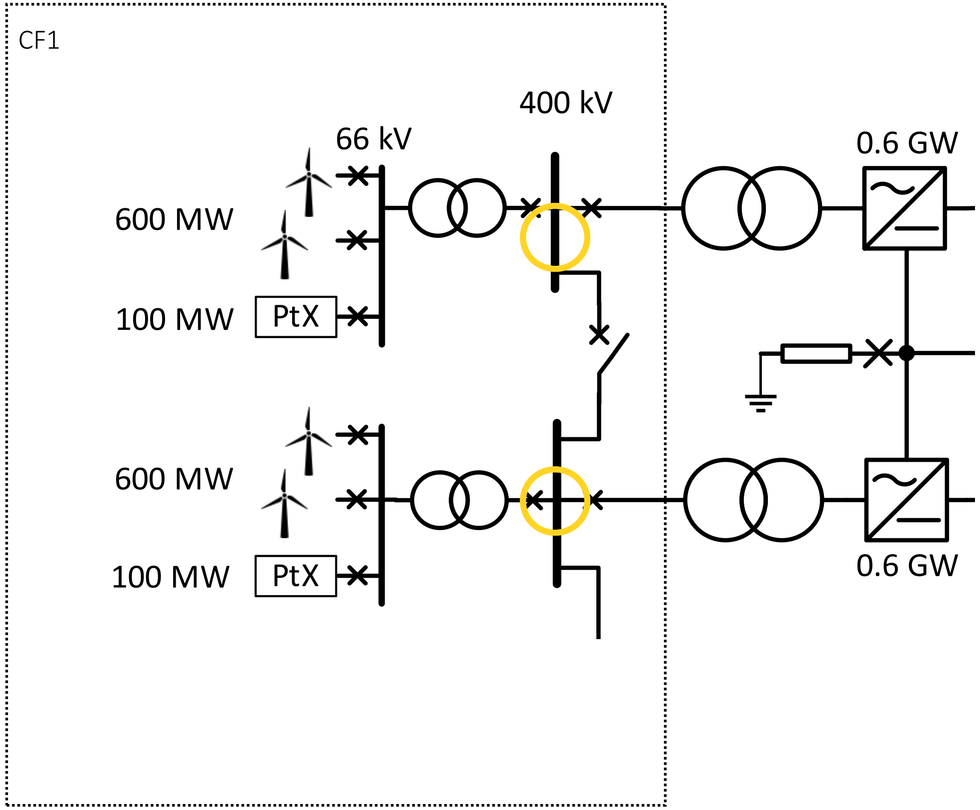
- Compliance
  - In all Normal Modes of Operation
  - Coupled operation
    - Combined response of the facility at PoC
    - A combined facility is not allowed to exchange P or Q through the 400 kV system



OPERATION OF BEI

Coupling modes in Normal Operation

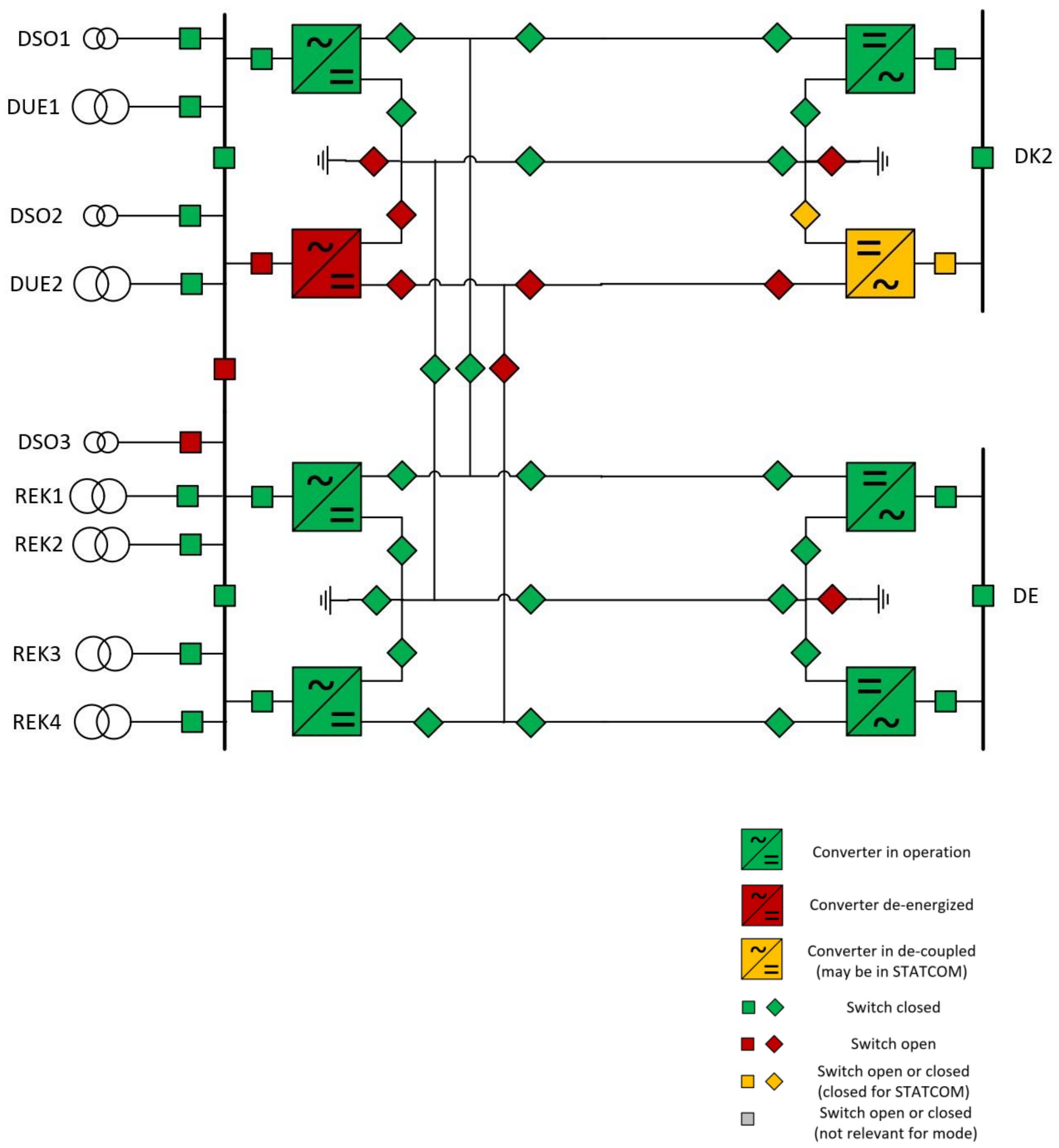
- Compliance
  - In all Normal Modes of Operation
  - Coupled operation
    - Combined response of the facility at PoC
    - A combined facility is not allowed to exchange P or Q through the 400 kV system
  - Decoupled operation
    - Compliance for requirements will be scaled to the exchange capacity of the individual bay sections
    - Power Quality requirements are the same in Coupled and Decoupled operation



OPERATION OF BEI

Coupling modes in Reduced Operation

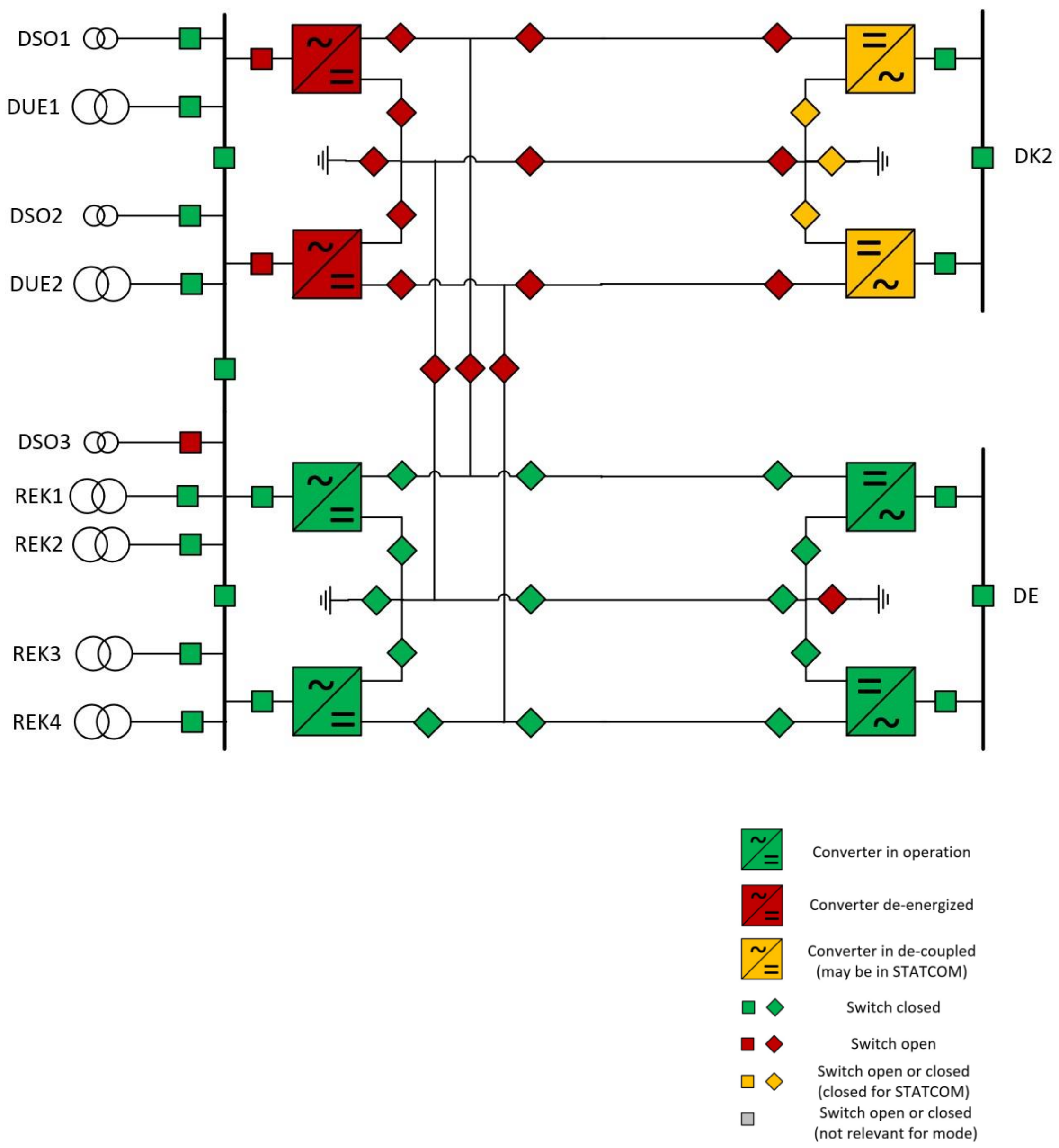
- Reduced operation is when the system capacity available is reduced for the Combined facilities
- Details of functionality is investigated in the design phase according to "Multi Party Interaction Study" process
- System stability is first priority for reduced operations



OPERATION OF BEI

Coupling modes in Reduced Operation

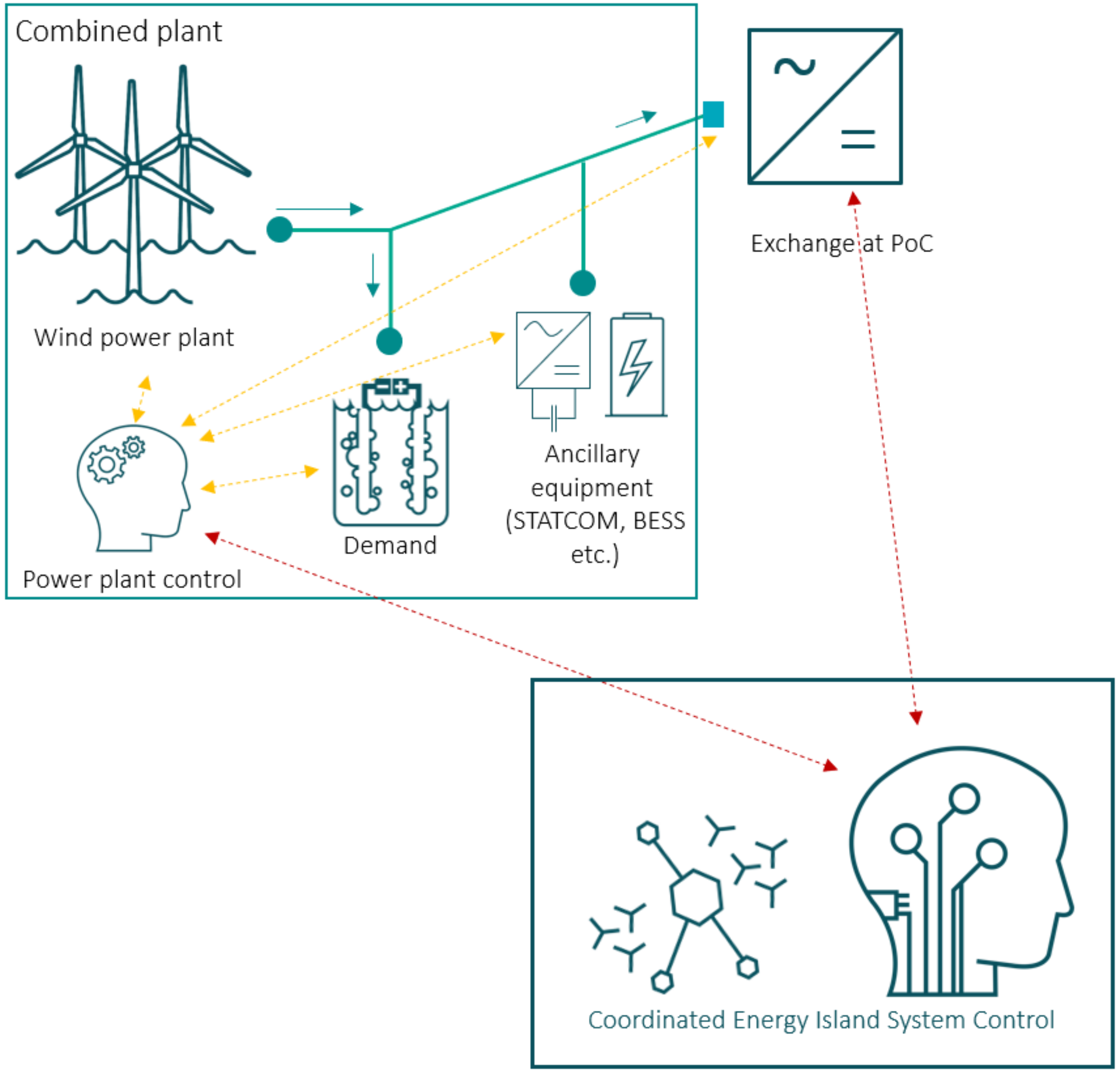
- Reduced operation is when the system capacity available is reduced for the Combined facilities
- Details of functionality is investigated in the design phase according to “Multi Party Interaction Study” process
- System stability is first priority for reduced operations



OPERATION OF BEI

Control System Interfaces

- SCADA: Power Schedules, remedial actions (if any)
- Market Platforms: MARI, PICASSO etc.
- Coordinated Energy Island System Control: EPC, P_{max}, cross-trip etc.
    - Only interface with the central power plant controller of the combined facility
    - Secondary control response
    - Main purpose to ensure stability and secure operation of the DC system
    - DC voltage setpoints, frequency setpoints, Active power limits, ramp rates, droops etc.



ENERGINET

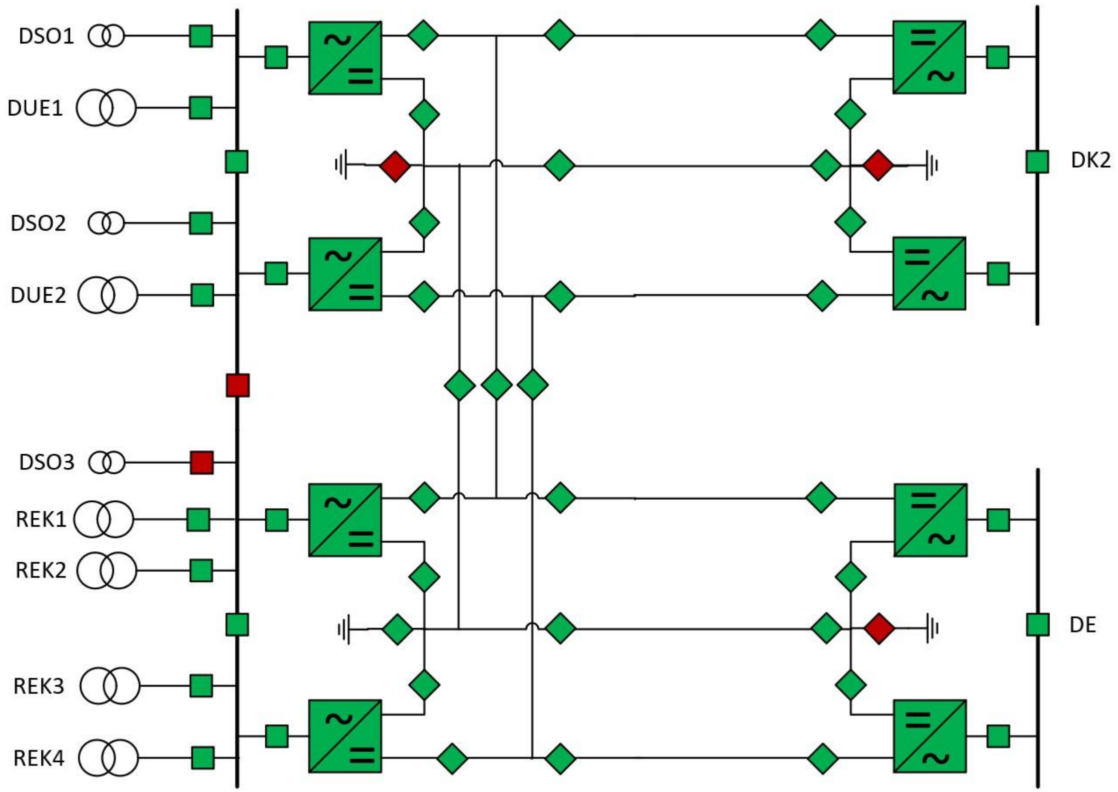
OPERATION OF BEI

Primary controls of the system

- A fully inverter-based system, an extreme case of the synchronous area systems

Primary Control mode strategy:

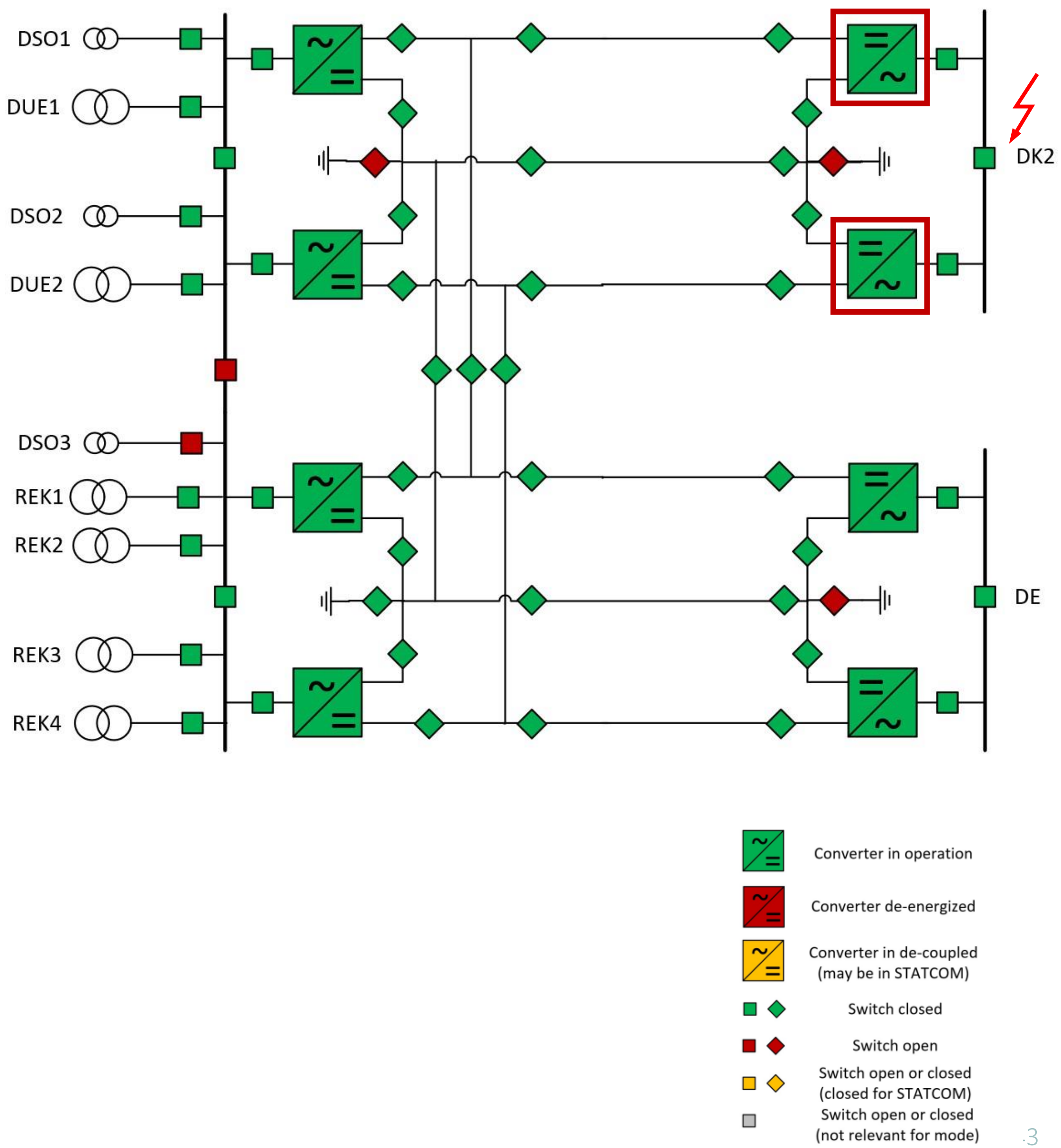
- Isolated AC system converters in Vac/f control
    - Crucial to coordinate wind and HVDC requirements
    - “weak” inverter-based system hence system more susceptible to changes than a synchronous area
- Synchronous area converters in Vdc/Vac control
    - To keep the DC voltage stability
    - To support the onshore system needs



OPERATION OF BEI

System needs in an Energy Island

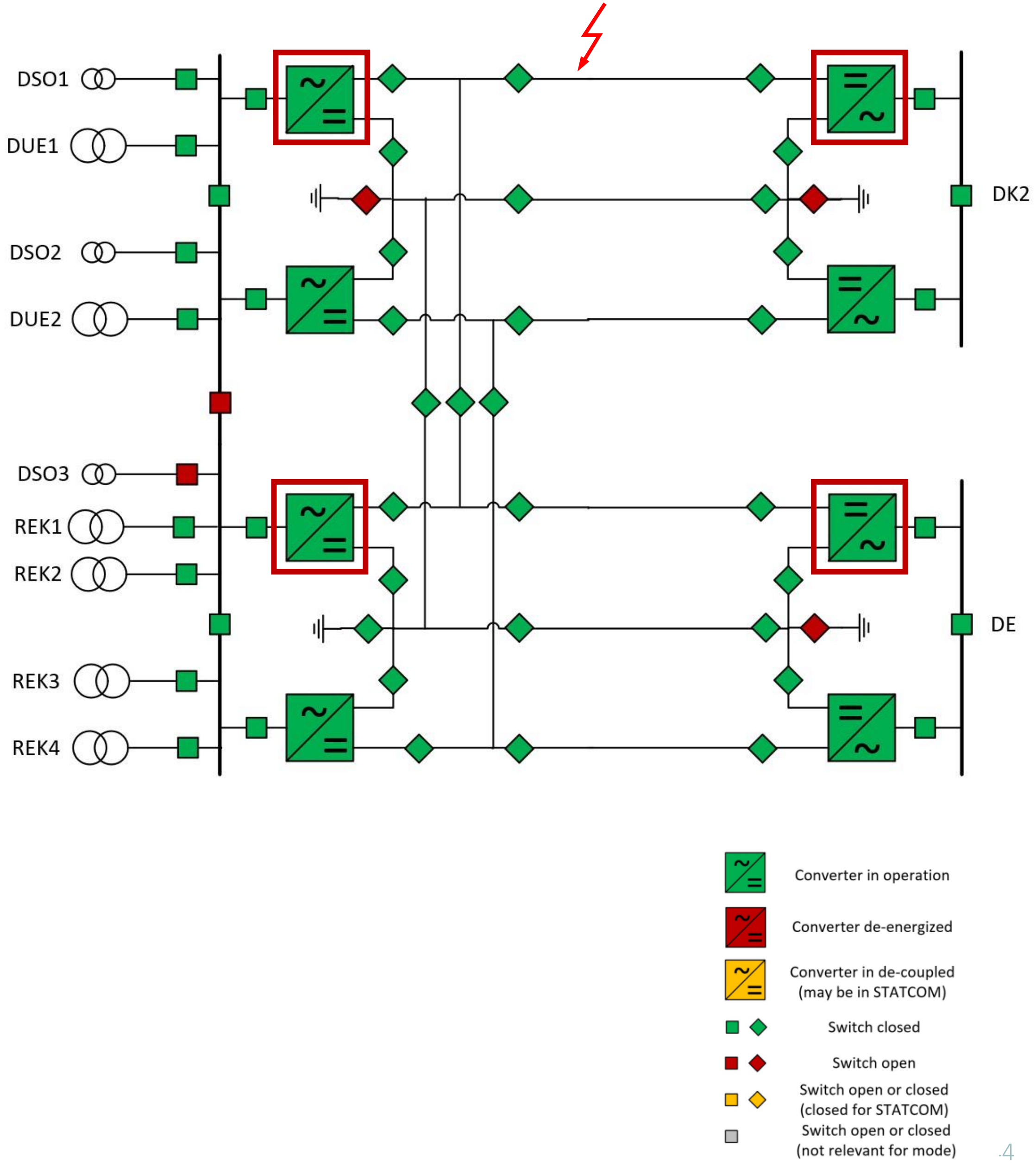
- Synchronous area faults – DC chopper to handle the power infeed



OPERATION OF BEI

System needs in an Energy Island

- Synchronous area faults – DC chopper to handle the power infeed
- DC faults – overload of healthy converter pole; need for wind ramp down or cross-trip



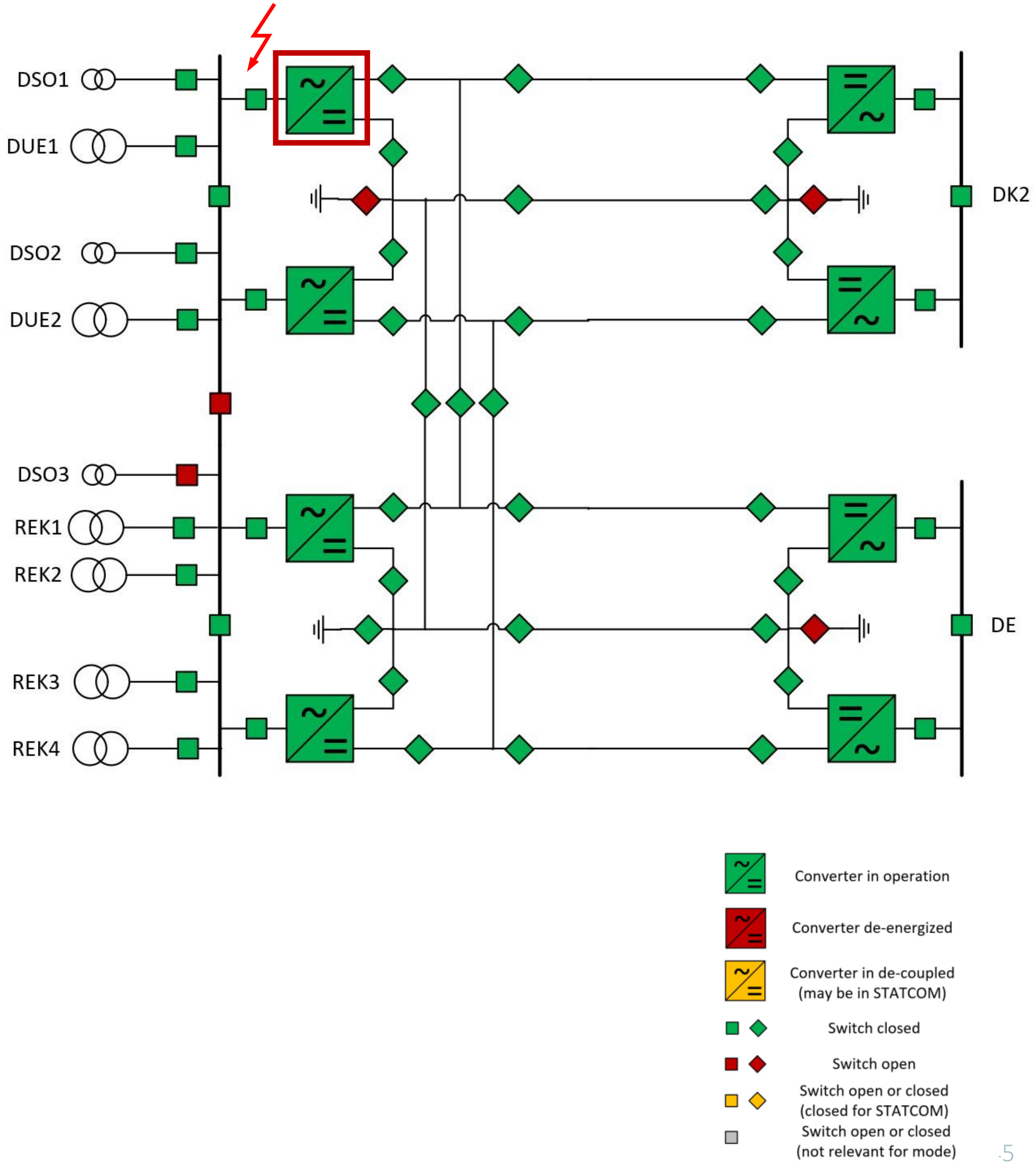
ENERGINET

ENERGINET

OPERATION OF BEI

System needs in an Energy Island

- Synchronous area faults – DC chopper to handle the power infeed
- DC faults – overload of healthy converter pole; need for wind ramp down or cross-trip
- Isolated AC system faults:
  - AC busbar fault – FRT capability
  - Converter internal fault – overload of healthy converter pole; need for wind ramp down or cross-trip

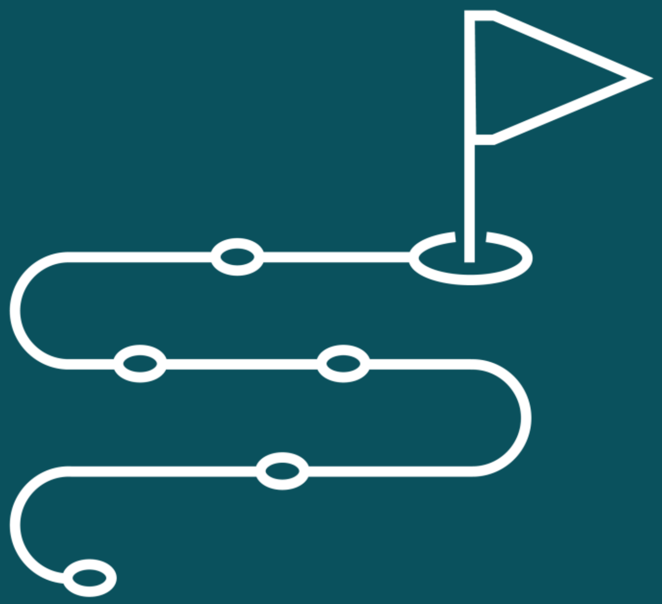


DE-RISKING THE PROJECT

Initiatives taken in the project

- International standards and collaboration
- Developed Model sharing framework
- Interaction studies
- Simplification of Operational Modes
- 1 Vendor for HVDC

PAUSE



COMPLIANCE PROCESS

Sebastian Bille Sørensen

Power System Design

COMPLIANCE PROCESS

Overview

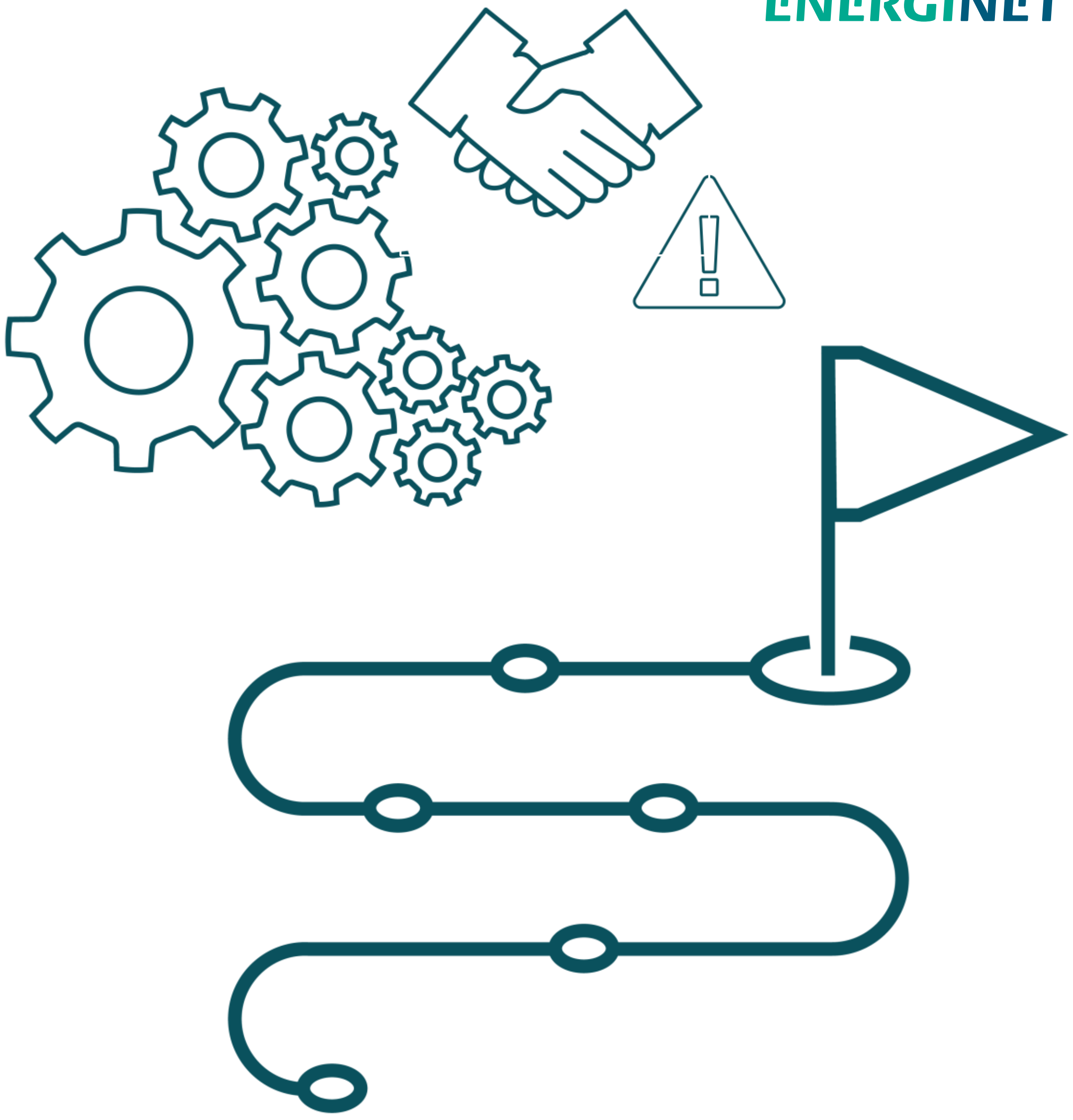
How to de-risk Bornholm energy island and ensure stability of system operation:

- Model requirements
- Compliance validation
- Multi-party studies
- Model & data sharing

These areas are described in detail in the references listed in appendix 1.A section 6.7.

- The aim of the presentation is to function as a reading guideline. Hence the documents will not be covered in detail.

ENERGINET



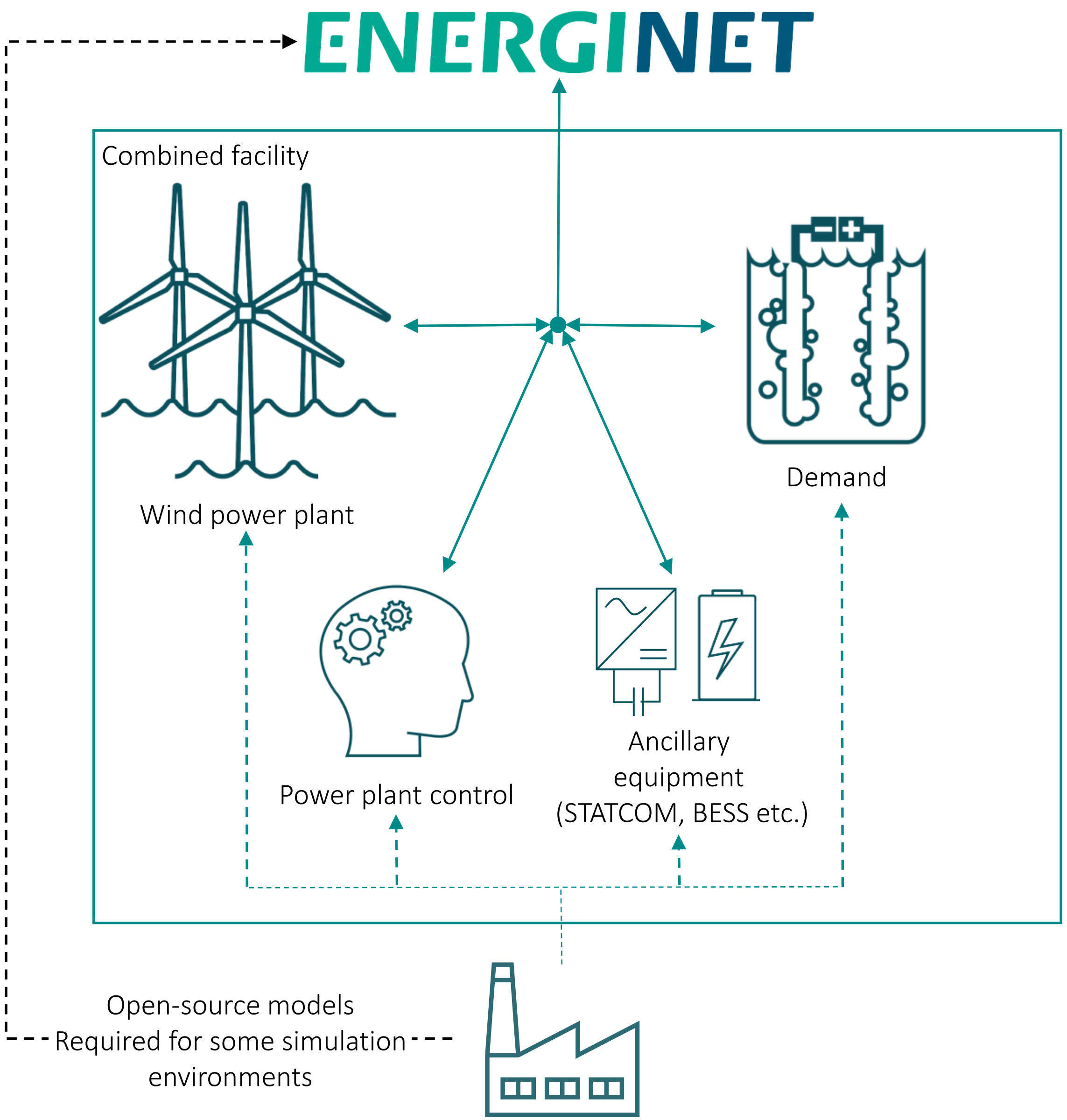
MODEL REQUIREMENTS

Compliance process

The combined facility is delivered as one model for each of the following types:

- Standard model types
  - Phasor-domain transient (PDT)
  - Electromagnetic transient (EMT)
  - Harmonic models
- New model types (BEI amendments)
  - Small-signal
  - Real-time simulation

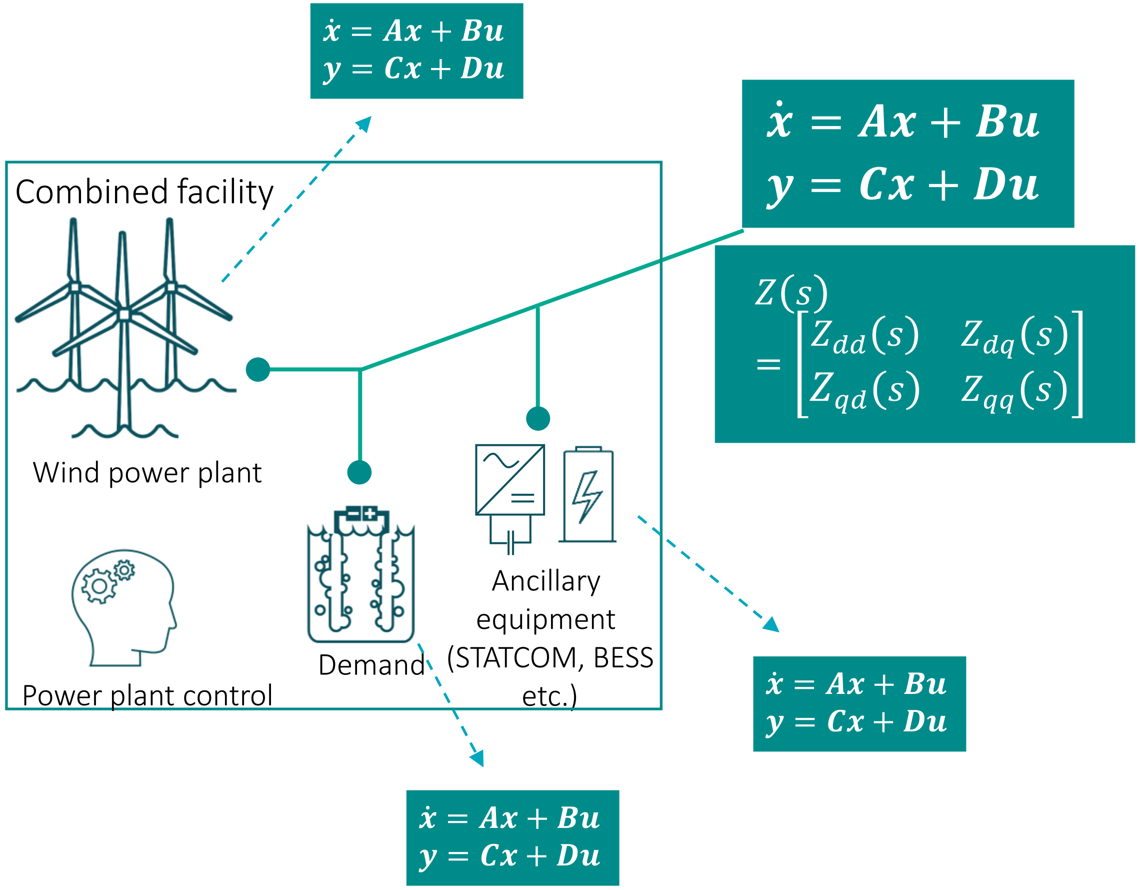
The models must be able to represent all possible operating points including combined and individual operation of the facilities



MODEL REQUIREMENTS

New model types

- Small-signal models in two forms:
  - State space form
  - Transfer function form, e.g. impedance
- Small-signal models must be provided for:
  - Full model representing the combined facility
  - Unit models representing each type; WTG, PtX etc.
- Small-signal models are used for root cause analysis by investigating system modes and dominant factors.

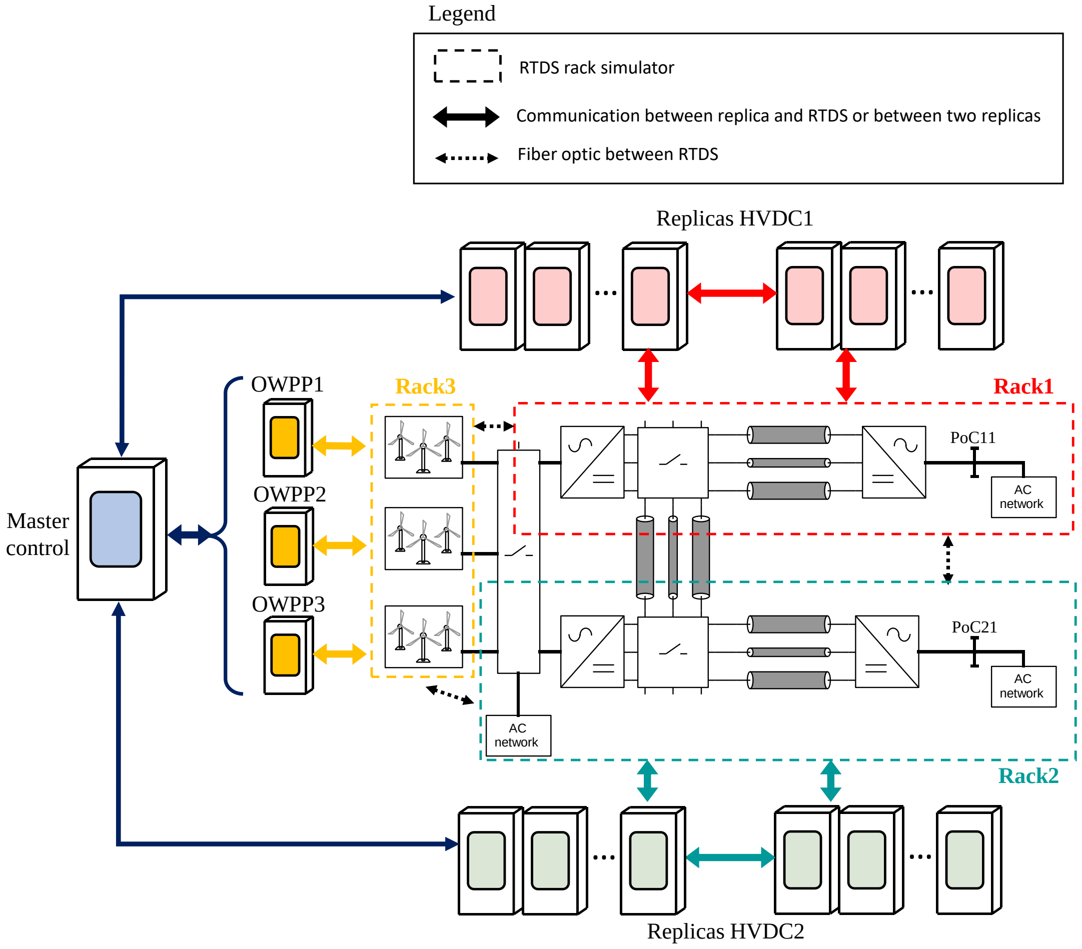


ENERGINET

MODEL REQUIREMENTS

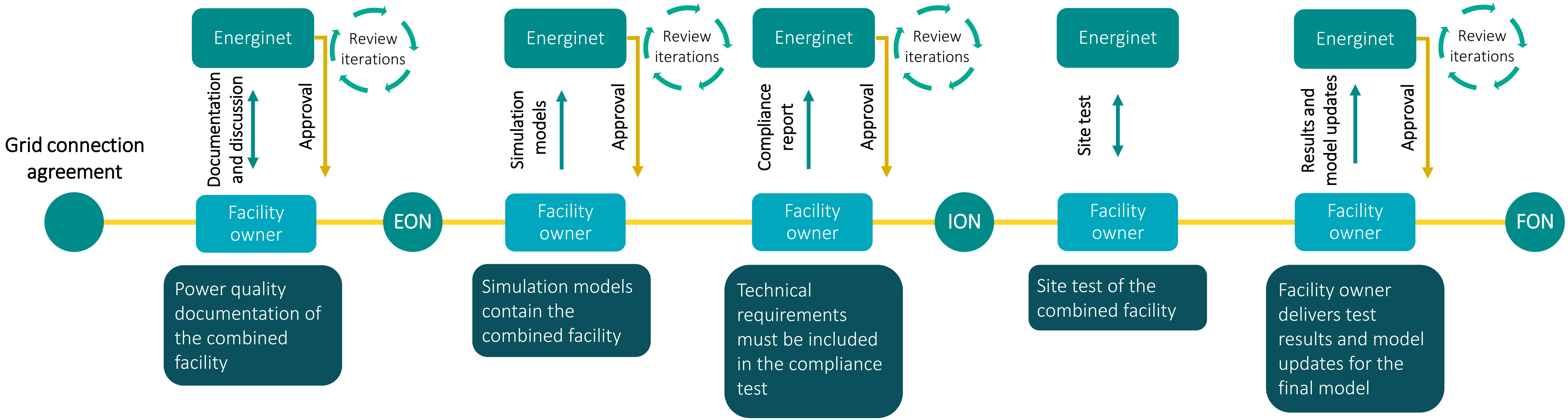
New model types

- A real-time simulation facility will be dedicated to Bornholm energy island. Can be Energinet or third-party lab.
- Real-time simulation models:
  - Replica based on HiL and/or SiL.
- The real-time simulation model must represent the combined facility, including demand units and ancillary equipment
- Real-time simulations are used to complement the offline EMT simulations and further de-risk the project with dynamic studies of even higher accuracy.
- The real-time simulation facility is further intended as training platform for operation.



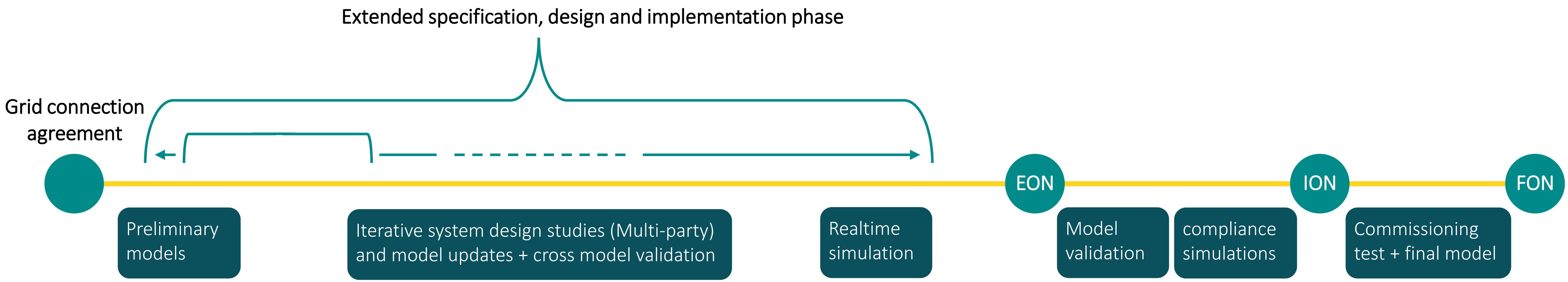
COMPLIANCE VALIDATION

The typical process



COMPLIANCE VALIDATION

The new process



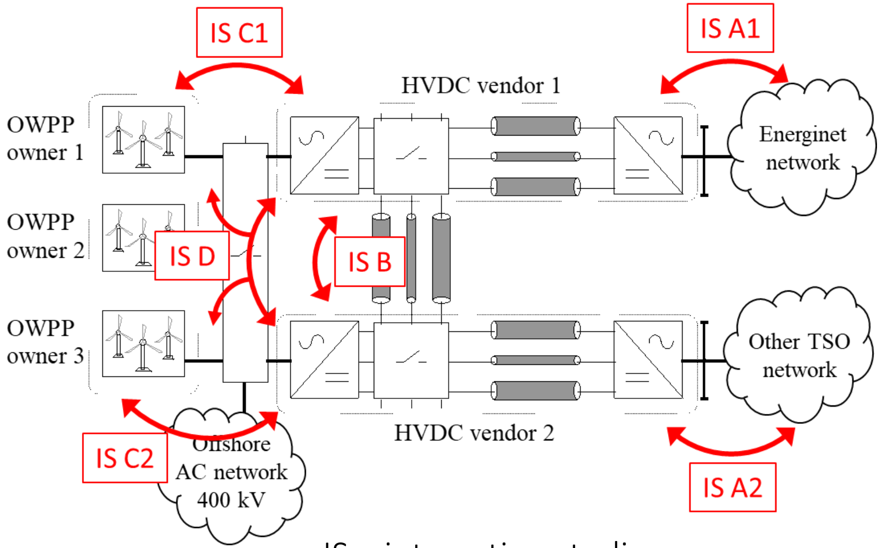
HIGH-LEVEL CONCEPT

- Operation Notification Procedure as usual
- Iterative model deliveries and studies
- High focus on mitigating potential interactions between wind-HVDC and wind-wind.
- Study process in joined cooperation between all parties

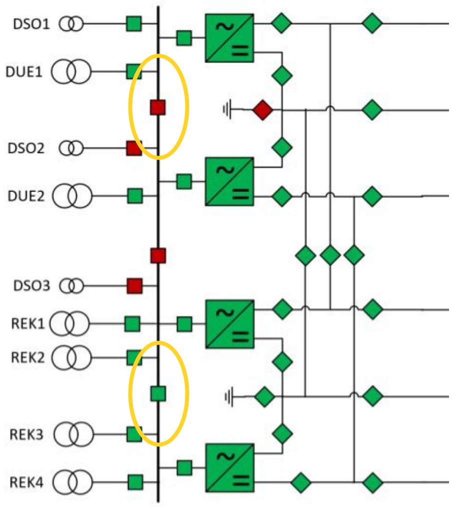
MULTI-PARTY STUDIES

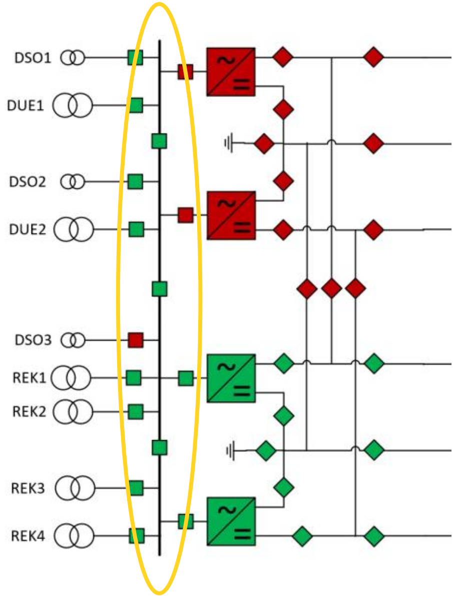
Motivation and purpose

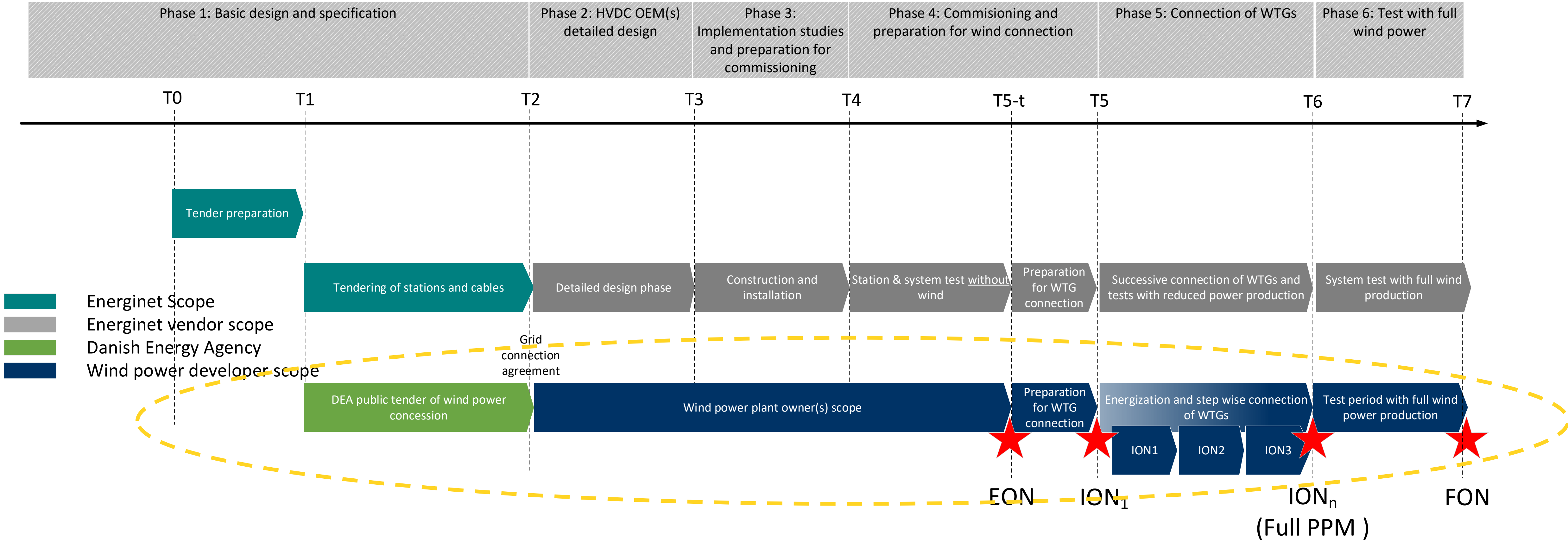
- Energinet has identified the main locations of interactions that need to be studied.
  - IS C and IS D are related to Combined Facility
- Each IS will be studied several times with different models, depending on the project stage.
- IS's needs to be studied for all operation regimes and relevant facility topologies. Number of variations must be limited to manage design complexity.
- The interactions studies cover the following, but not limited to:
  - Large and small disturbances.
  - Frequency and voltage control coordination.
  - Harmonic performance.
  - AC protection.



IS – interaction studies





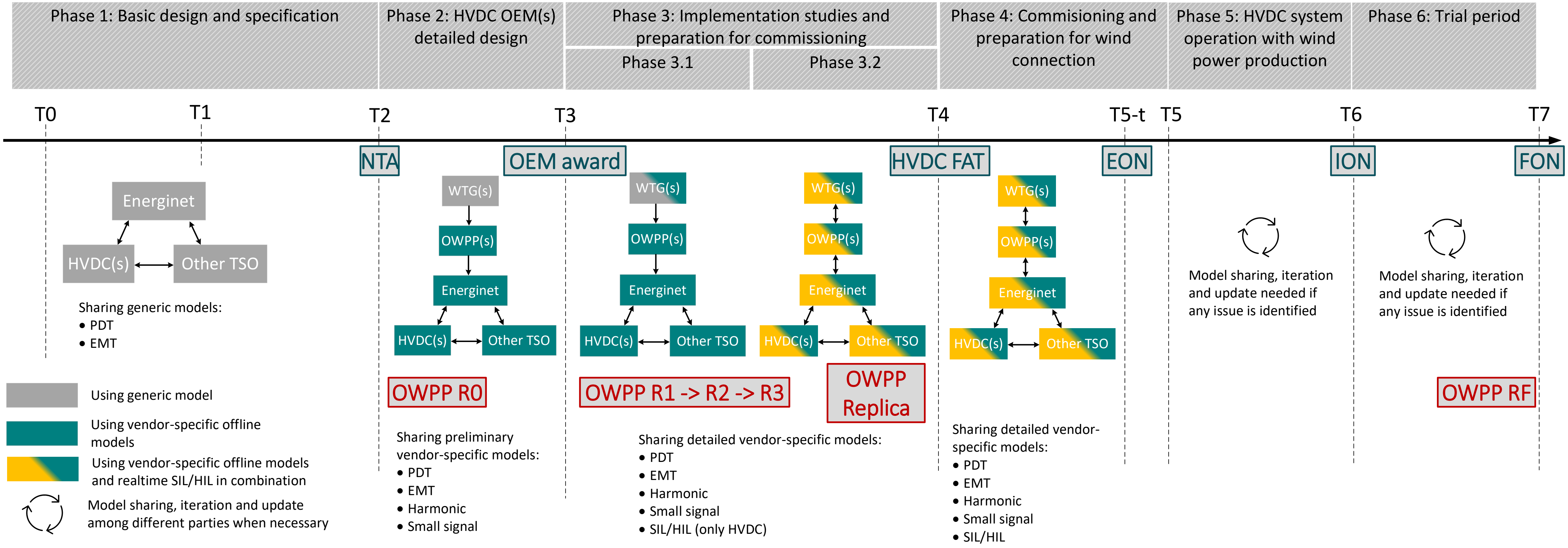


MULTI-PARTY STUDIES

Project timeline & studies

- Exact dates are not detailed.
- Instead, model deliveries are based on project phases and milestones.

Study phase		Description	Milestone	
Phase 1	Specification	Basic design and specification study phase.	T2	Tender and awarding of HVDC EPC contract
Phase 2	Implementation	HVDC OEM detailed design phase	T3	Design gate for HVDC OEMs and onboarding of WTG OEM
Phase 3	Implementation	Implementation studies and preparation for commissioning	T4	Ready for onsite commissioning of HVDC
Phase 4	Operation	Commissioning and on-site testing of multi-vendor HVDC system	T5	Energization of wind power plant (EON)
Phase 5	Operation	HVDC system test with wind power production	T6	Full wind power production (ION)
Phase 6	Operation	Trial operation of HVDC and wind power with full wind power generation	T7	Final operational notification (FON)



MULTI-PARTY STUDIES

Model upgrades and sharing

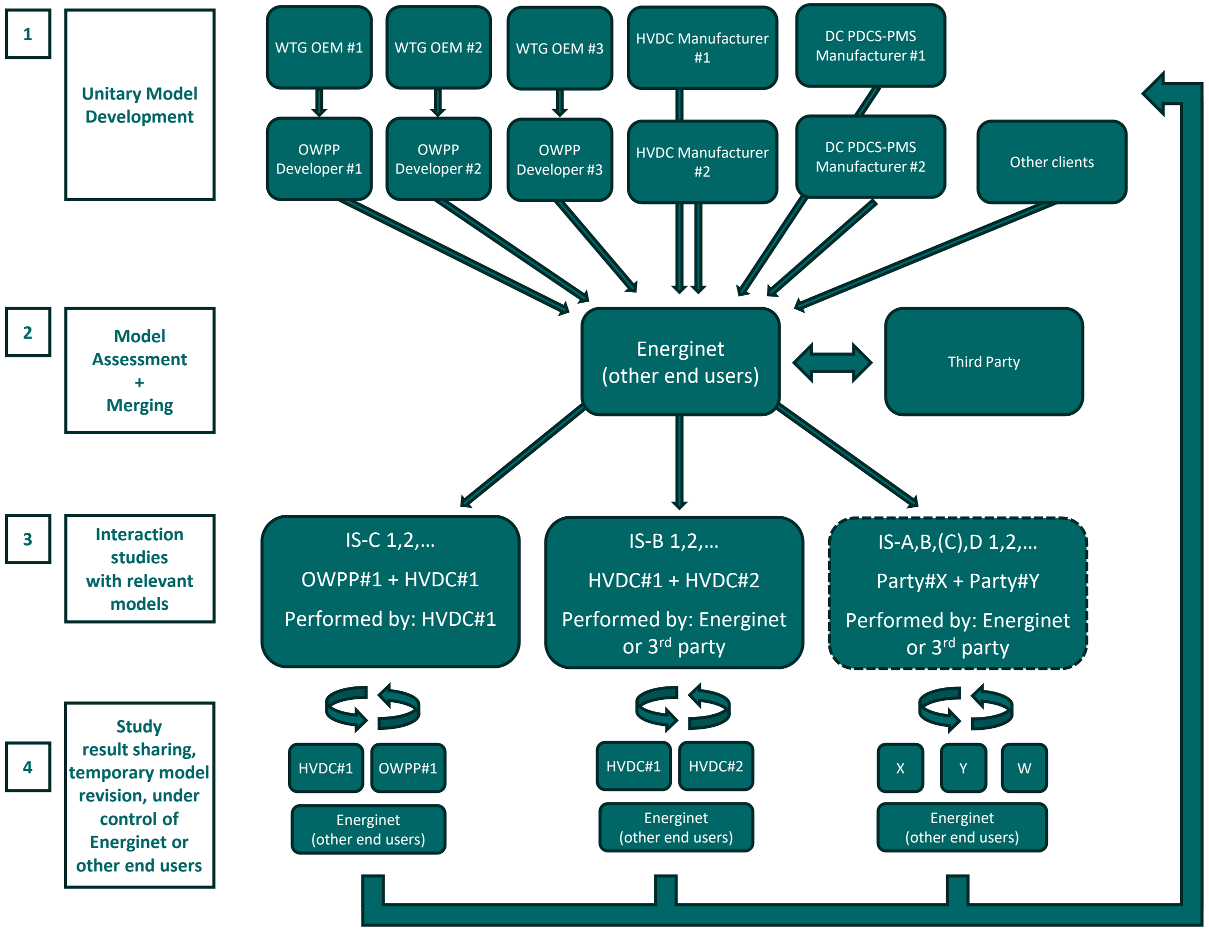
- The "multi-party studies" document lists all the relevant areas of study and describes the objectives and purpose of each. The exact simulations and tests to be conducted will be detailed during the project by cooperation of all parties.

- All parties are involved in model sharing and system studies from beginning of phase 3.
- Model accuracy to rise following project phases
- The study process is designed to ensure models of sufficient accuracy are available, relevant to the phenomena in scope of different project phases. And to align the model sharing with study needs of different stakeholders.

MULTI-PARTY STUDIES

Model and data sharing framework

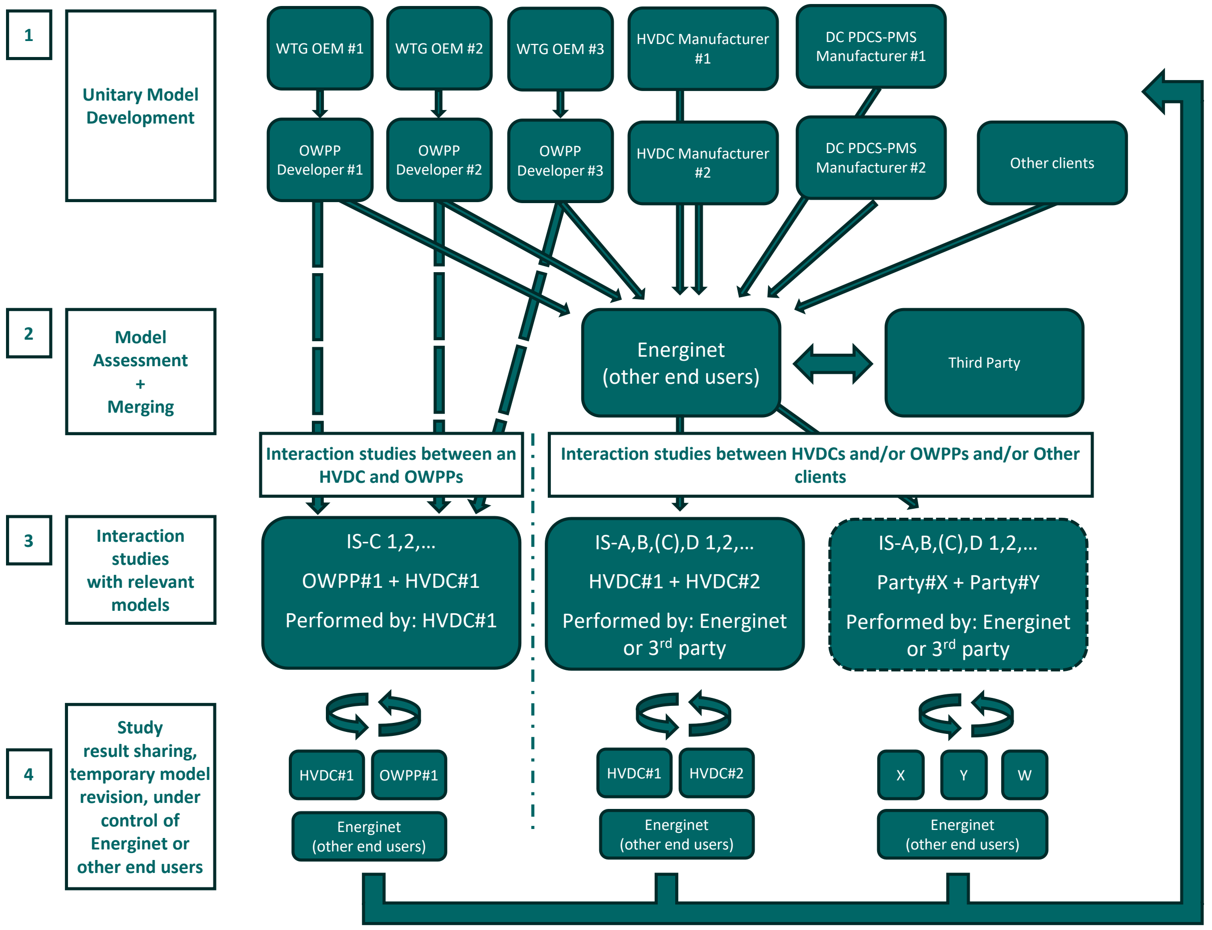
- The document is currently written on a generic level for how to handle multiple HVDC manufactures and OWPP developers.
- Option A:
    - Energinet or third-party is central to the interaction studies or model sharing



MULTI-PARTY STUDIES

Model and data sharing framework

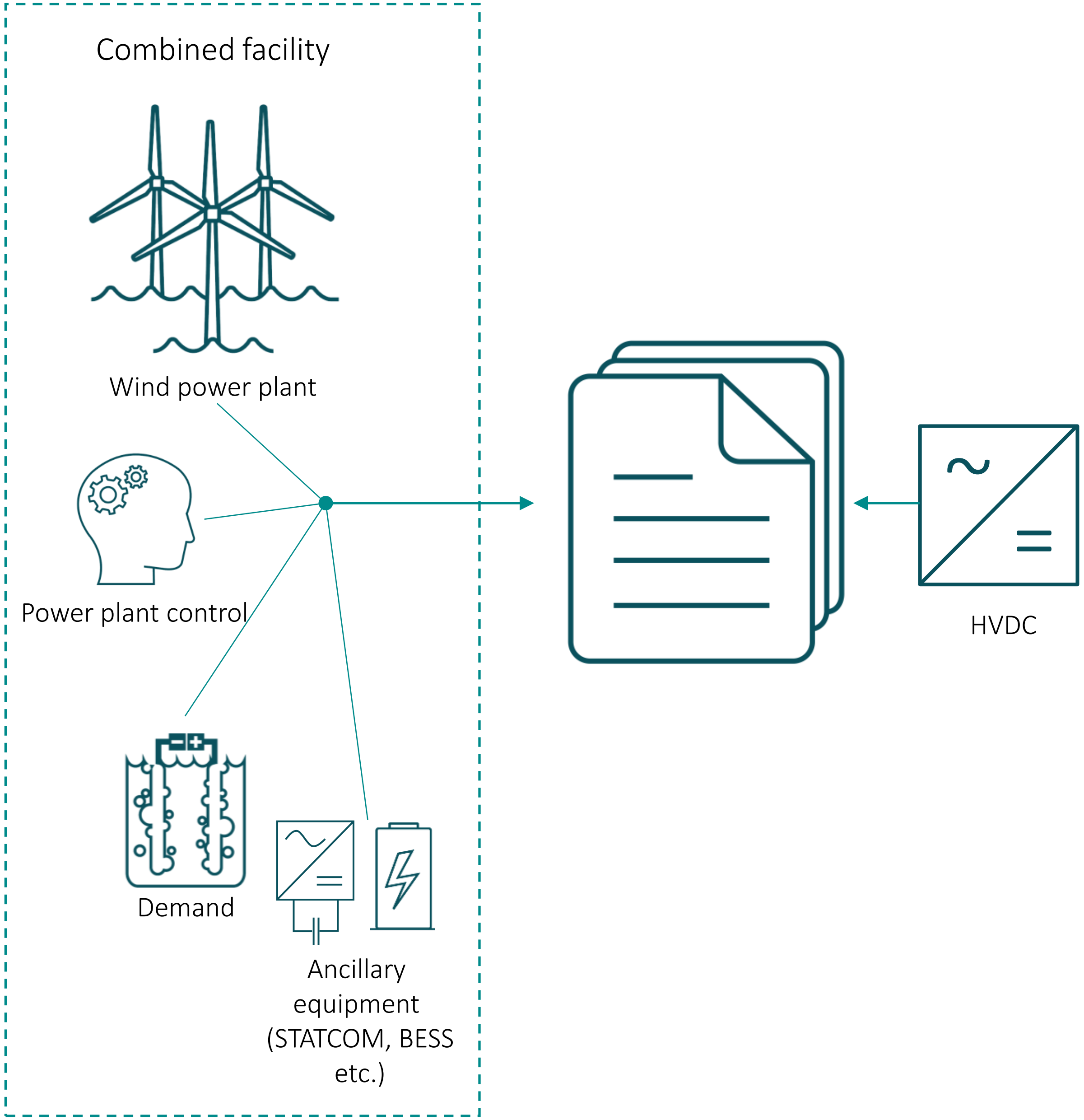
- The document is currently written on a generic level for how to handle multiple HVDC manufactures and OWPP developers.
- Option A:
  - Energinet or third-party is central to the interaction studies or model sharing
- Option B:
  - HVDC manufacturer is central to the interaction studies between HVDC and facilities. Meaning models of windfarms etc. is delivered to HVDC manufacturer.
- Energinet prefers option B. However, we are interested to know the opinions of developers and OEMs.



MULTI-PARTY STUDIES

Model and data sharing framework

- Model sharing policy
  - The models shared between developers, OEMS and HVDC can be more restrictive than models to Energinet.
  - Energinet can keep models and use them as needed with no expiration
  - Developers & OEMS can only use models for a strict scope of work defined by all parties under supervision of Energinet.
    - It is not allowed to keep models or copies when the task is finished, or work stopped.



PAUSE

TECHNICAL REQUIREMENTS

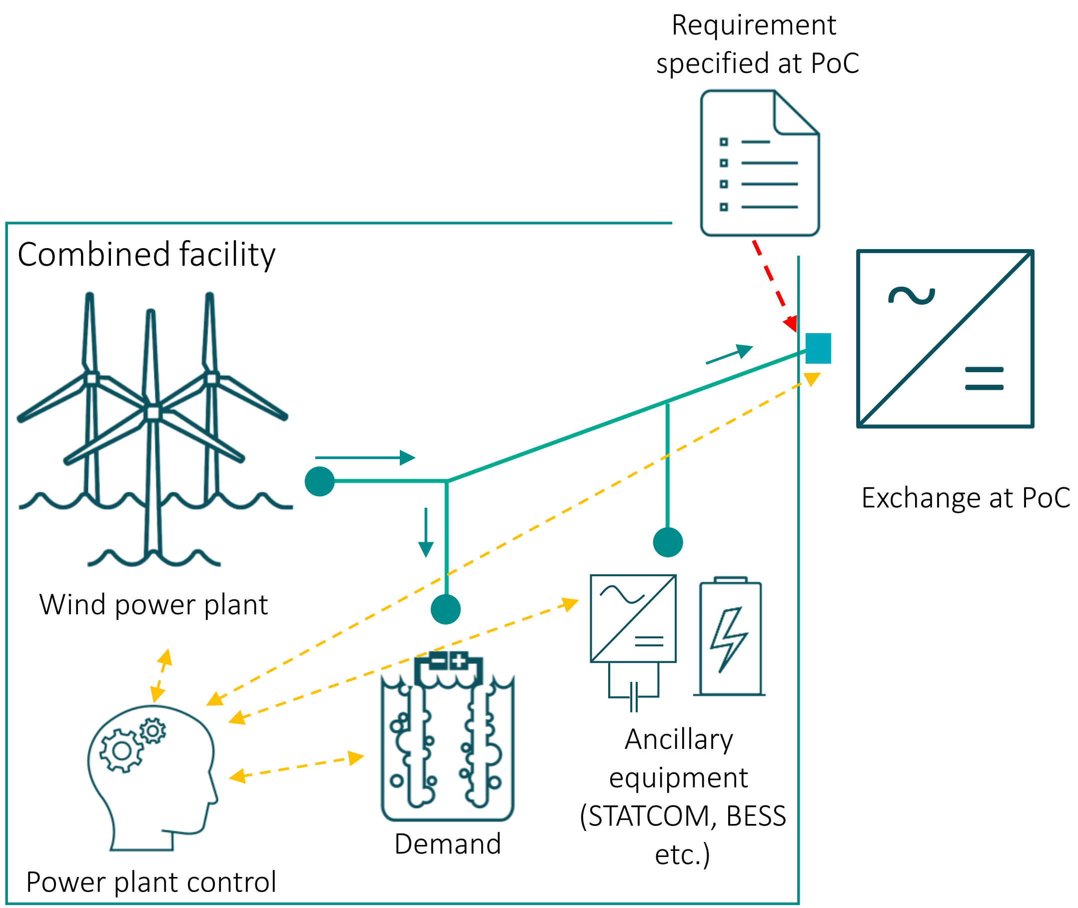
Sebastian Bille Sørensen

Power System Design

TECHNICAL REQUIREMENTS

Appendix 1.A - introduction

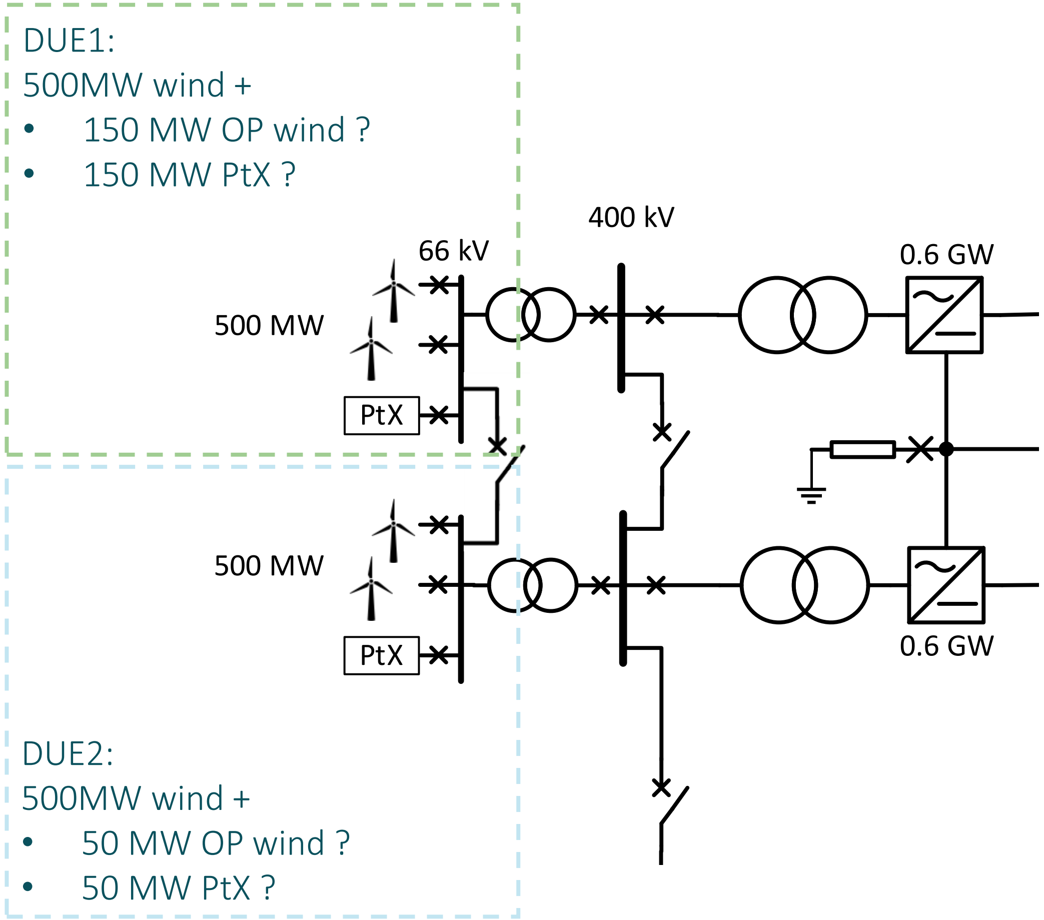
- The technical requirements are not covered extensively and in high detail. The aim is to clarify and debate the principles and ideas behind the technical requirements.
- The observer should take special notice of:
  - The majority of the technical requirements are specified and evaluated in the PoC unless specified otherwise.
  - The exchange capacity at the PoC is the foundation of most of the technical requirements.
  - To the highest degree possible, it is optional how the technical requirements are satisfied.
- Key takeaways of each technical requirement are highlighted in yellow.



TECHNICAL REQUIREMENTS

Co-location and overplanting

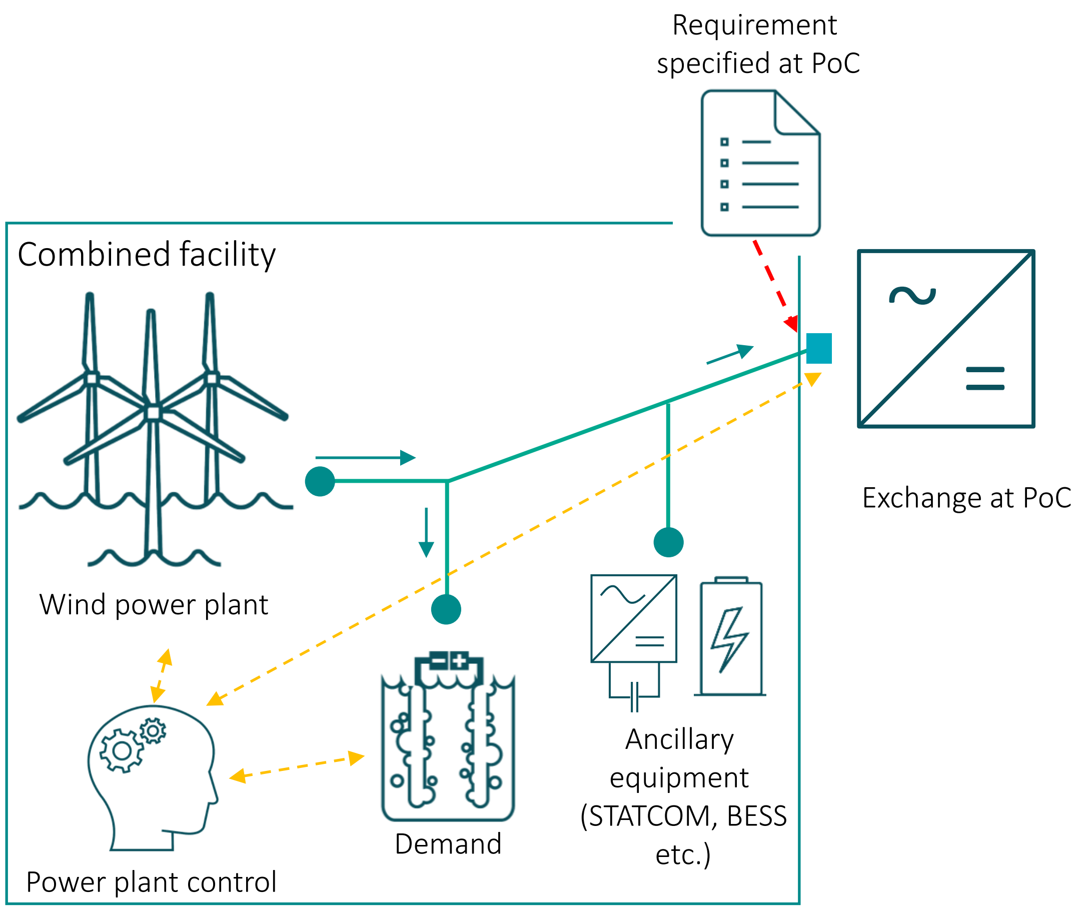
- The topology of each facility and AC sections are essential for the full system design and HVDC control tuning. Therefore:
  - Combined facility design must be decided no later than delivery of “OWPP R0” models, at beginning of phase 2.
  - The topology of different sections when de-coupled must be fixed.
  - Sections is defined per HVDC converter AC busbar.



TECHNICAL REQUIREMENTS

Co-location and overplanting

- Requirements are designed to ensure combined facility response at POC is like a “normal” wind power plant with rating matching the exchange capacity.
- Therefore, several existing requirements are applicable to the combined facility at POC:
  - Voltage and frequency ranges.
  - Robustness: FRT, OV-FRT, phase jumps & ROCOF.
  - Regulation of active power, LFSM, fault current.
- The exchange capacity should be used for requirements which are based on a facility nominal power.
- Measurements, recordings and signals mainly at POC, requirements to be updated specifying monitoring of individual facilities



Connection to BEI

Specific functional requirements

INTERCONNECTIONS, DECOUPLING & PROTECTION SCHEMES

REACTIVE POWER

POST FAULT ACTIVE POWER RECOVERY

EPC & AUTOMATIC CURTAILMENT

EXCHANGE LIMITATIONS

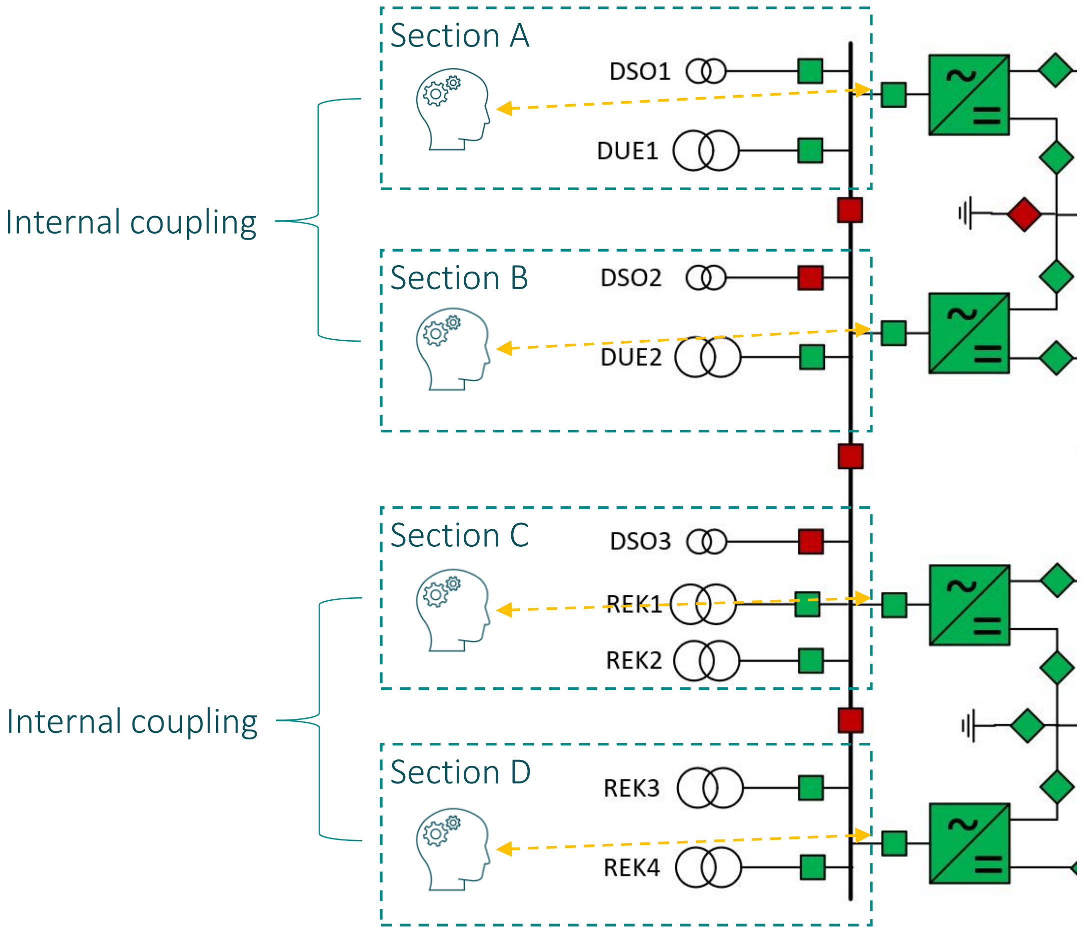
CROSS TRIP & SYNCHRONIZATION

ENERGINET

INTERCONNECTIONS & DECOUPLING

Technical requirements

- The facilities are allowed to have possibility of internal couplings between different sections.
- The sections are not allowed to be internally coupled when the system is operated with main 400kV busbars de-coupled.
- Each section must be able to operate fully as an independent facility, being compliant with all requirements at POC.
- When decoupled, compliance is based on the exchange capacity for requirements such as:
  - Reactive power capability & Fast fault current
  - Droops and tolerances for LFSM, voltage control etc.
  - Emergency power control & exchange limitations



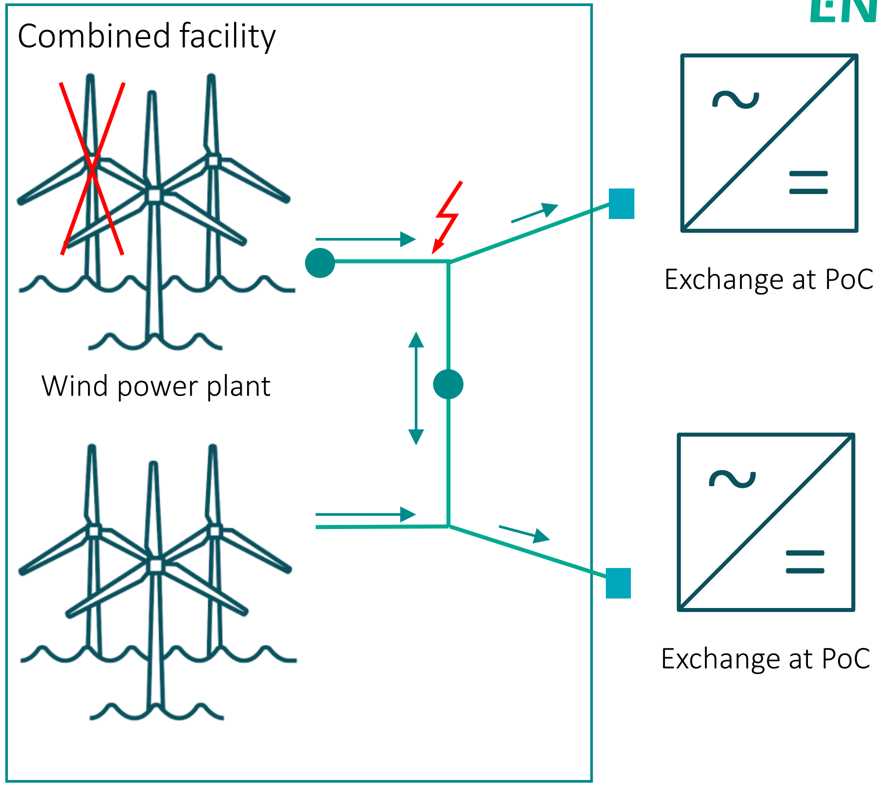
INTERCONNECTIONS & PROTECTION SCHEMES

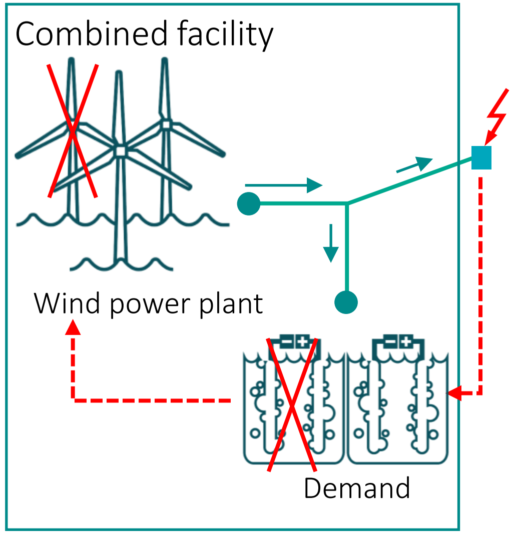
Technical requirements

Contingencies must be covered by reserves for largest unit in the power system:

- BEI: 600 MW

- Especially relevant with large degree of overplanting
- Topology and protection of the plant must be designed and operated to satisfy the requirements of maximum loss of generation and demand due to an individual fault.
- This is regardless of the system operational regime and status of internal electrical couplings.

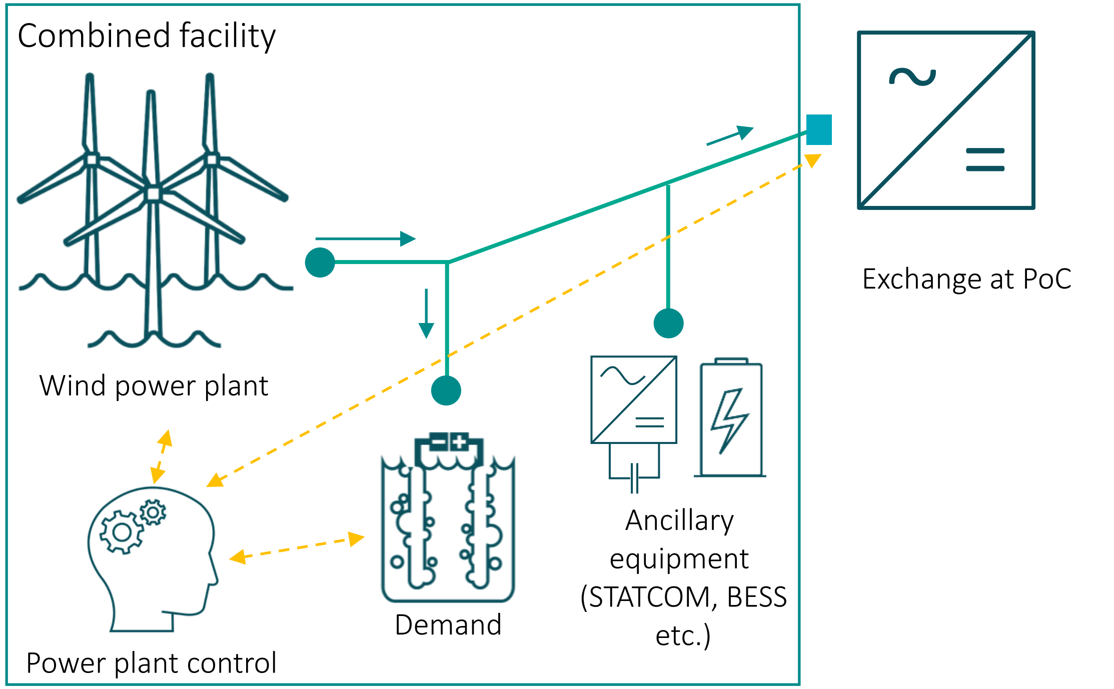


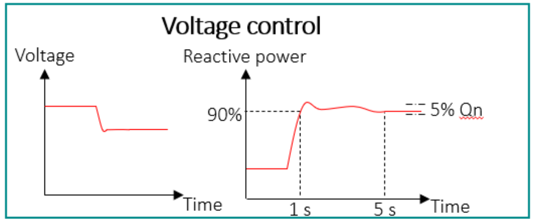


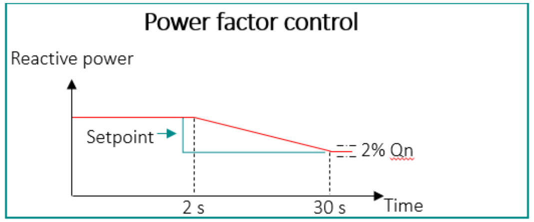
REACTIVE POWER CONTROL MODES

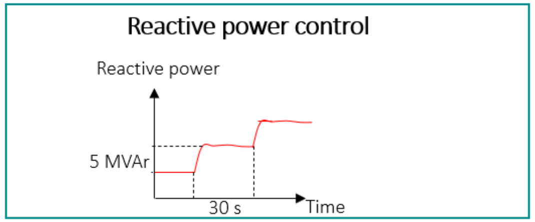
Technical requirements

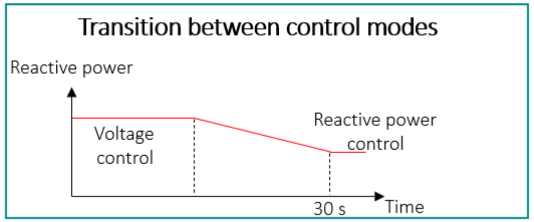
- The combined facility must follow the RfG requirement for control modes at PoC
  - Reactive power control
  - Voltage control
  - Power Factor control
- The requirement does not specify which component that provides the control capability, but it must be valid for all operation scenarios
- Transition between components performing the control must be smooth







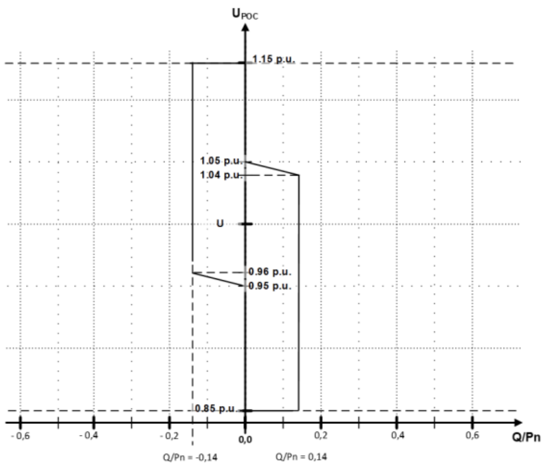


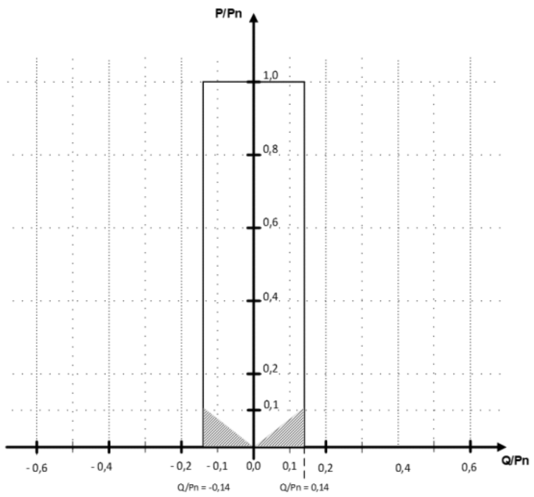


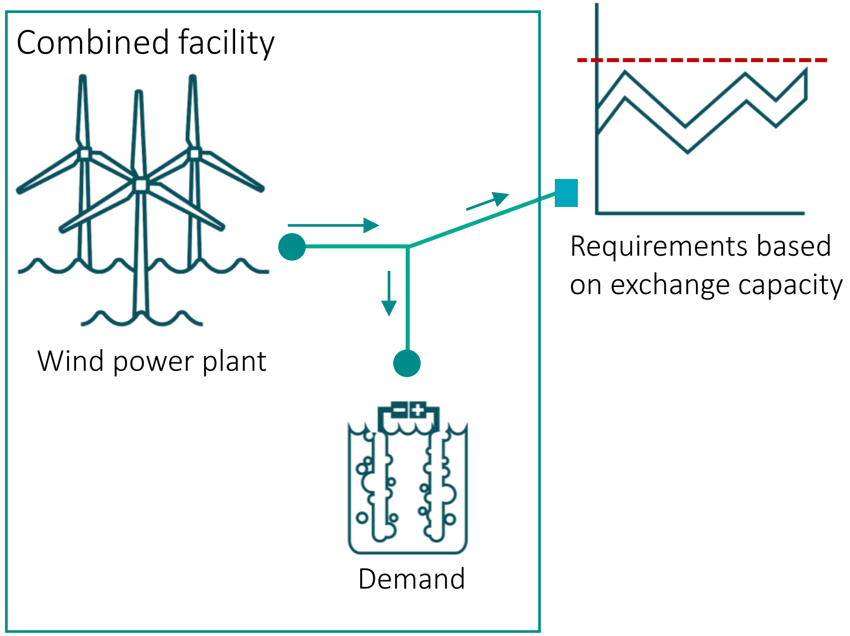
REACTIVE POWER CAPABILITY

Technical requirements

- The combined facility must follow the appendix 1.A section 4.5 requirement at PoC.
- Reactive power capability based on exchange capacity
- The requirement does not specify which component is required to deliver reactive power capability which allows for design freedom
- The reactive power capability is valid for all operation scenarios and limited availability is only accepted if a reduced number of units are in operation.
- The reactive power capability is reduced in amount compared to RfG, but U-Q/Pn is extended to full voltage range.







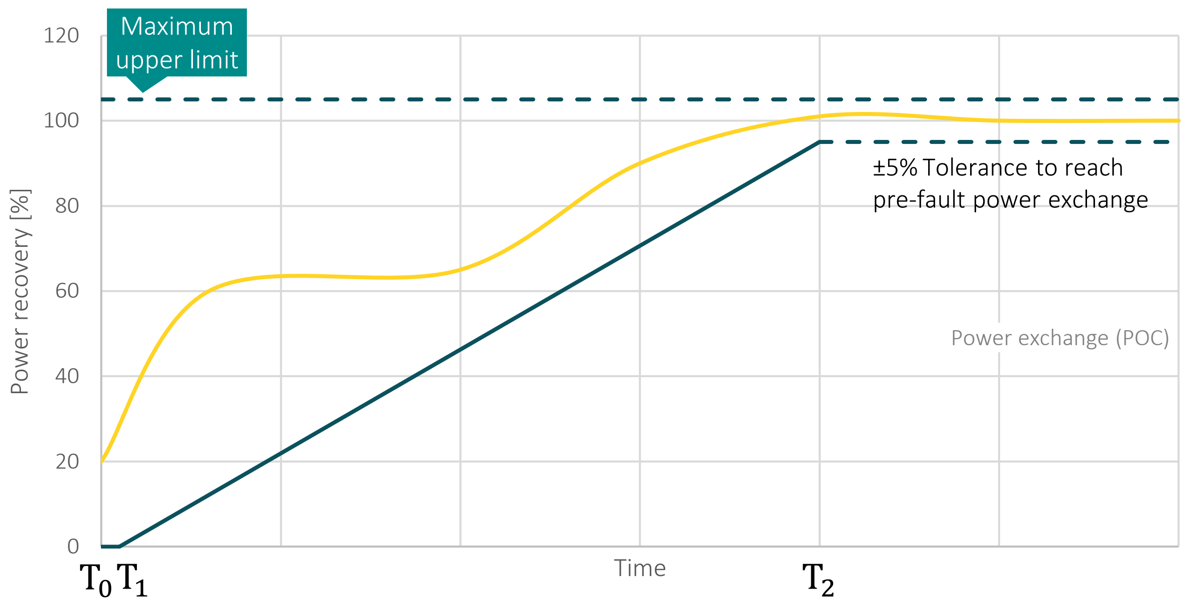
POST FAULT ACTIVE POWER RECOVERY

Technical requirements

- The combined facility must follow the RfG requirement* at PoC based on exchange capacity
- Energinet does not specify requirements for individual facilities to allow highest degree of design choice to fulfil technical requirements at PoC
- Two different PFAPR functions:
  - Normal – T_2 maximum 5 seconds.
  - Slow controlled response – T_2 in 5-20 seconds range (1 second resolution). Setting adjustable and chosen by Energinet.

*A slow PFAPR response is submitted as part of RfG updates, but included directly in appendix 1.A

PFAPR requirements for combined facility



- T_0: Voltage at PoC back at normal operation.
- T_1: 0-500 milliseconds depending on need to avoid FRT toggling.
- T_2: < 5 seconds or 5-20 seconds. The time is specified by Energinet based on the need at PoC.

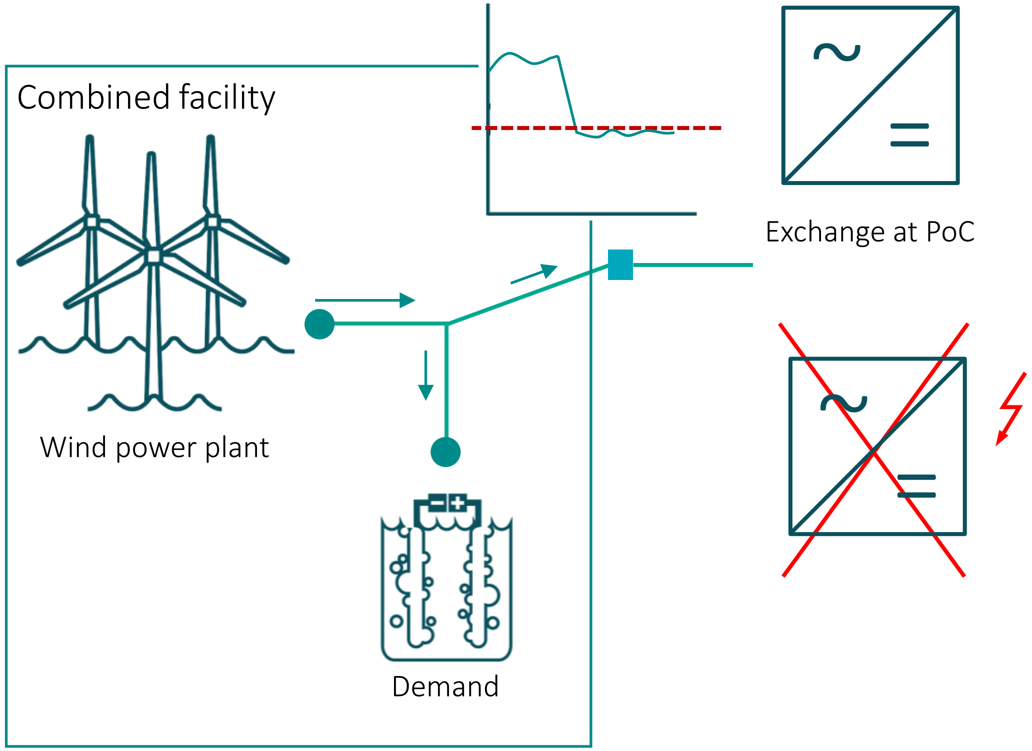
EMERGENCY POWER CONTROL

Technical requirements

- Automatic regulation in case of faults in the power system which would otherwise result in excessive overloading
- The combined facility must follow the EPC requirement at PoC based on exchange capacity
- Regulation signal communicated to the combined plant. Regulation can be down or upregulation of either of the individual facilities
- The EPC signal has top priority, and the new limit must be active within 100 ms after receiving the signal.

Expected default steps	Active power limit, based on exchange capacity
1	90%
2	80%
3	66%
4	60%
5	50%
6	33%
7	25%
8	0% (plant must stay synchronized to AC system)

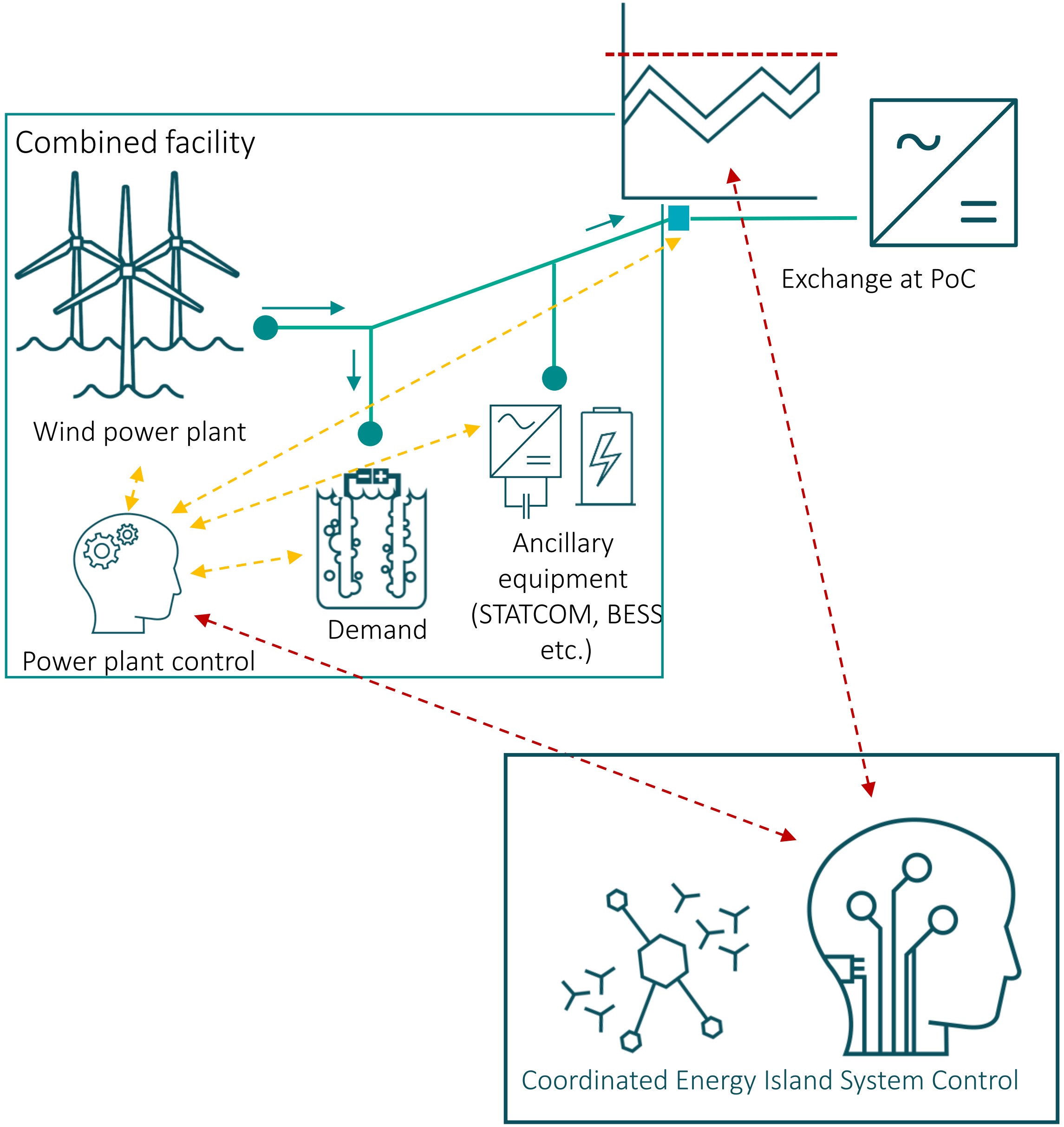
ENERGINET



AUTOMATIC CURTAILMENT

Technical requirements

- The combined facility must be able to receive and follow a continuous variable signal, setting the maximum allowed active power exchange.
  - The signal can take any value between 0-100 % of exchange capacity.
  - Down regulation must be initiated within 100ms.
  - Regulation ramp to be determined, not faster than 25%/s.
- The requirement for maximum exchange limitation after disturbance, is scaled based on the curtailment.

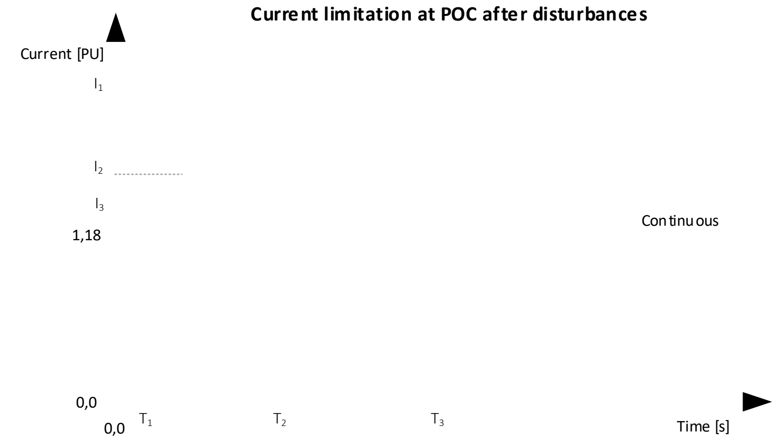


ENERGINET

EXCHANGE LIMITATIONS AT THE POINT OF CONNECTION

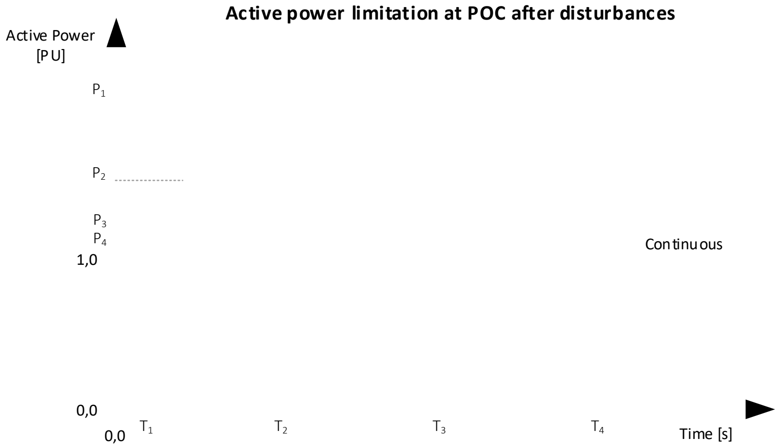
Technical requirements

- The combined facility should never violate exchange capacity. However, for special disturbances an upper limitation for current and active power is defined.
- This requirement does not give exemption from complying with:
  - Post fault active power recovery requirement
  - Fast fault current requirement
- The active power exchange limitation is scaled accordingly when the automatic curtailment signal is active.
- This requirement provides a limitation when not covered by other requirements



$$I_{nominel} = \frac{S_{PoC}}{\sqrt{3}\,U_n}$$

Time (s)		Power (pu)		current (pu)	
T_1	0.01	P_1	2.0	I_1	2.0
T_2	0.1	P_2	1.5	I_2	1.5
T_3	1.0	P_3	1.2	I_3	1.25
T_4	10.0	P_4	1.1	-	-

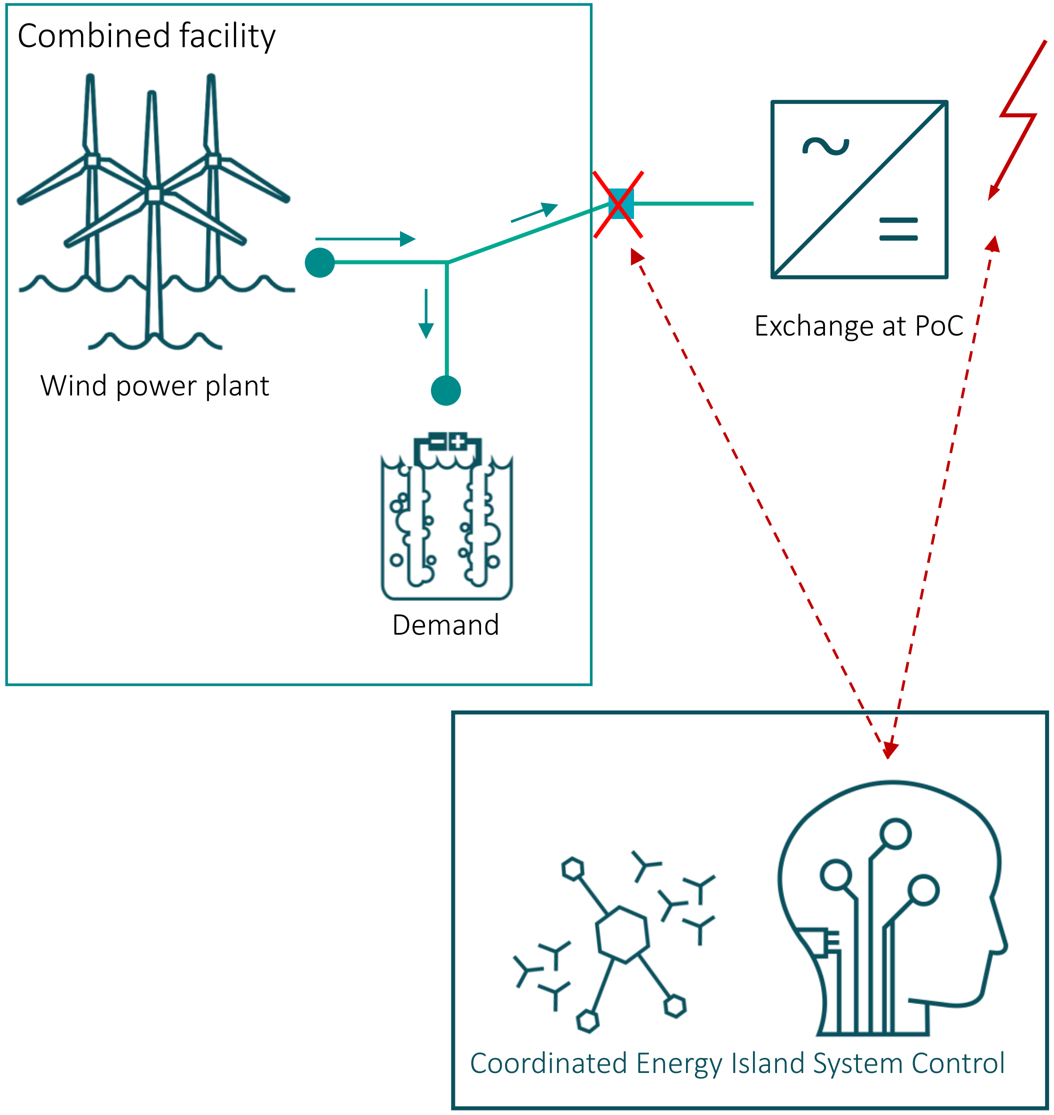


$$P_{nominel} = \text{allowed exchange}$$

CROSS TRIPPING & RESYNCHRONIZATION

Technical requirements

- Energinet can cross-trip circuit breakers in the interface point between facilities and the 400 kV substation in case of emergencies.
- This is meant as a last resort if:
  - Upper exchange limitations are violated
  - Or EPC did not have the desired effect.
- Following a forced or unintended disconnection, the combined facility must be ready to resynchronize and reach pre-trip active power levels within 15 minutes.
  - The 15 minutes, is from when system is back in normal operation
  - Normal active power ramp limits apply.



OPEN DISCUSSION

ENERGINET QUESTIONS FOR STAKEHOLDERS

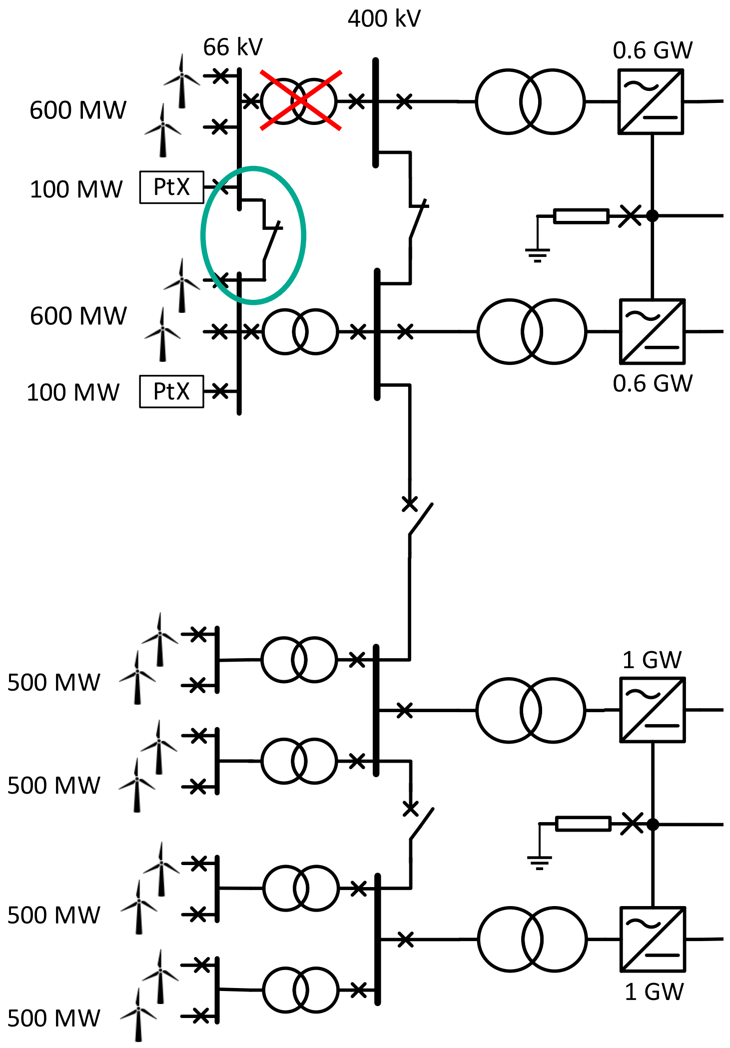
ENERGINET

WIND POWER PLANT'S OPERATION MODES

Value for developers

- Allowing parallel operation of the combined facility's medium voltage bays will affect HVDC design.
- Should it be allowed and under which conditions?
- What is the influence of overplanting and demand on the value of additional breakers?

Notice, that a successful design study will be required.

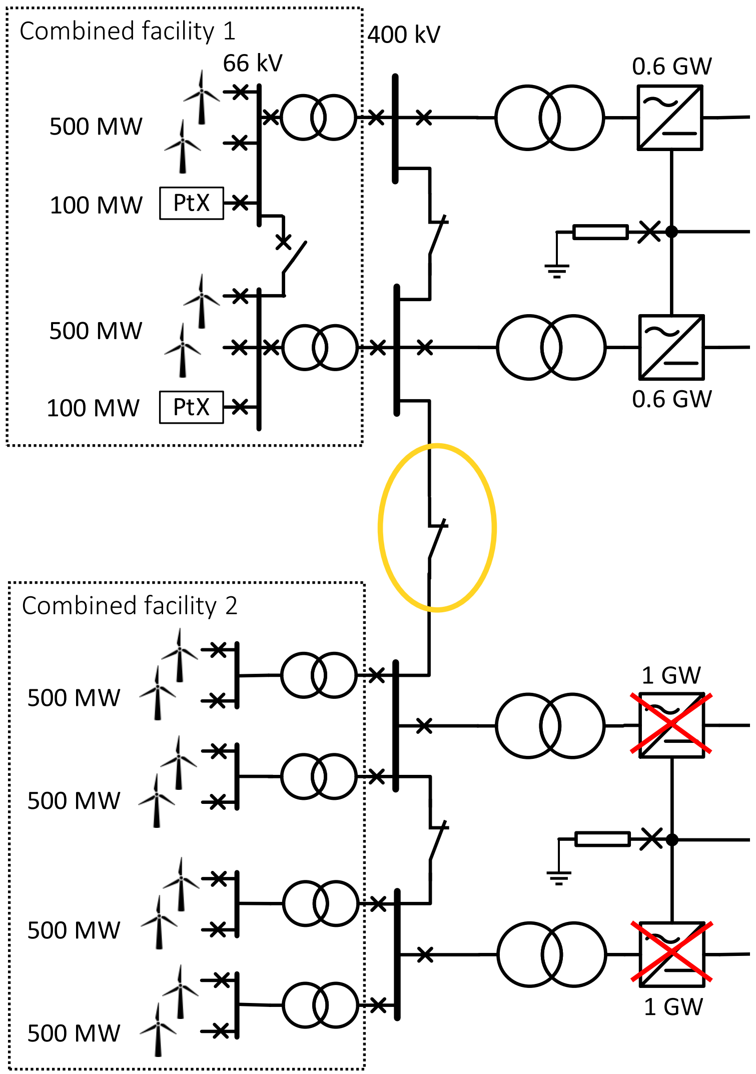


ENERGINET

WIND POWER PLANT'S OPERATION MODES

Value for developers

- Allowing parallel operation of the two combined facilities will affect HVDC design and will introduce additional need for coordination between wind developers.
- Should it be allowed and under which conditions?



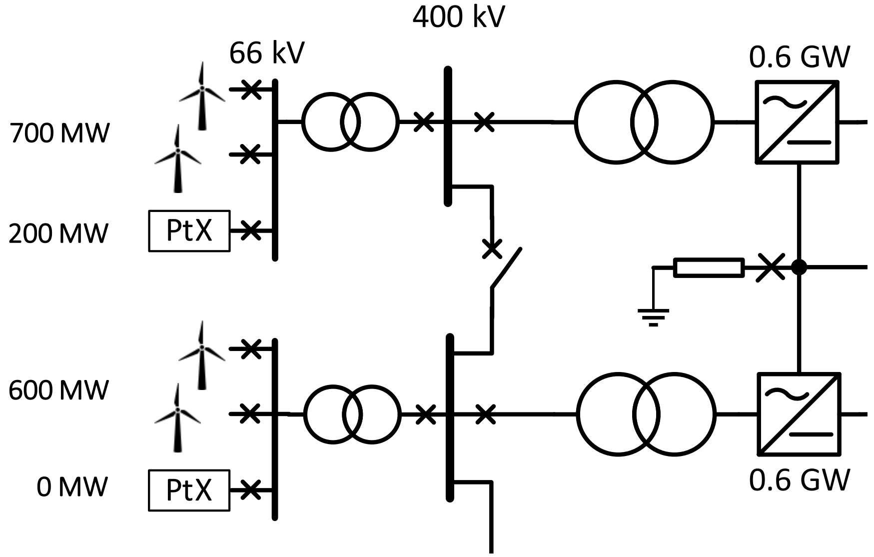
Notice, that a successful design study will be required.

ENERGINET

DISTRIBUTION OF OVERPLANTING AND DEMAND

Preferable configuration

- Is a certain distribution of the demand and hence overplanting preferable for developers?



Thank you

NEXT STEP

Comments on todays workshop

- Feel free to share your thoughts and comments on today's topic.
- Upload your comments in EU-supply via the message form or send an email to offshorewindfarms@ens.dk before Friday 13. Oktober 2023

Contract notice Energy Island Bornholm

-The DEA plan to start the procurement period by the end of 2023 or start of 2024.

It will be published via EU-supply.

Thank you