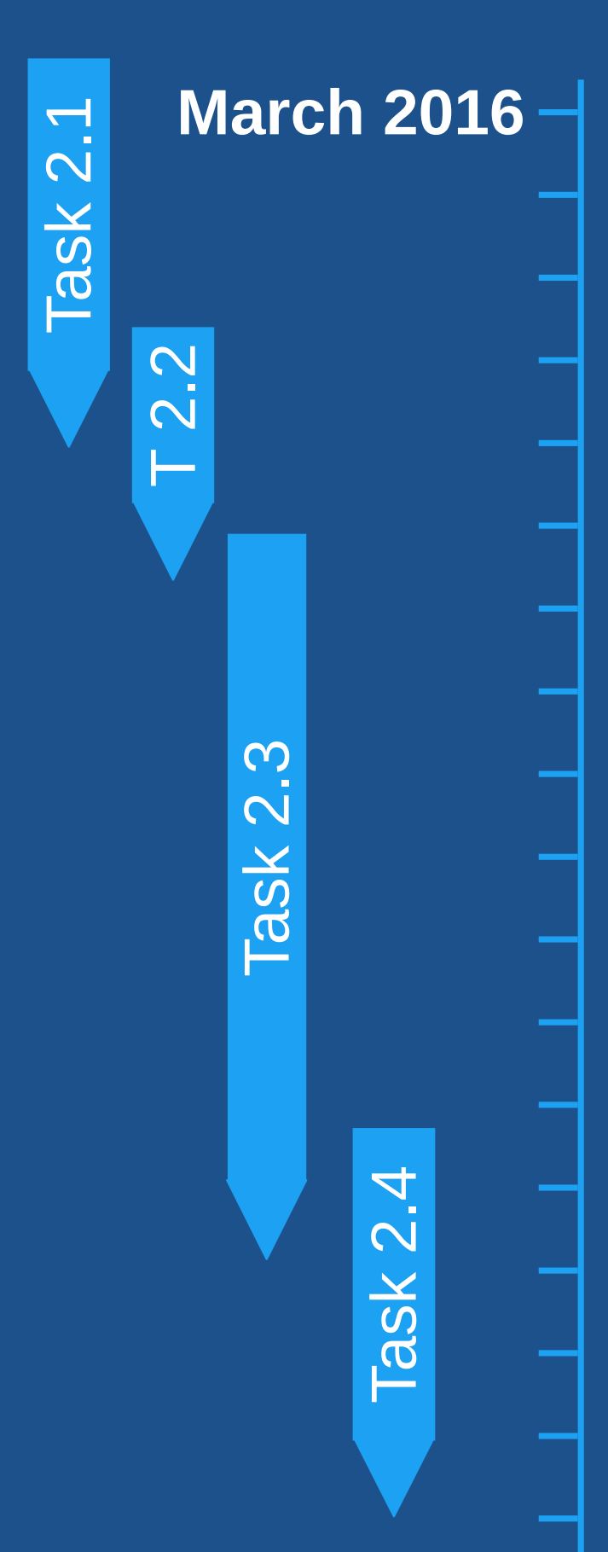
PROMOTioN
PROGRESS ON MESHED HVDC
OFFSHORE TRANSMISSION
NETWORKS

WP 2 – GRID TOPOLOGY AND CONVERTERS

Structure and Objectives



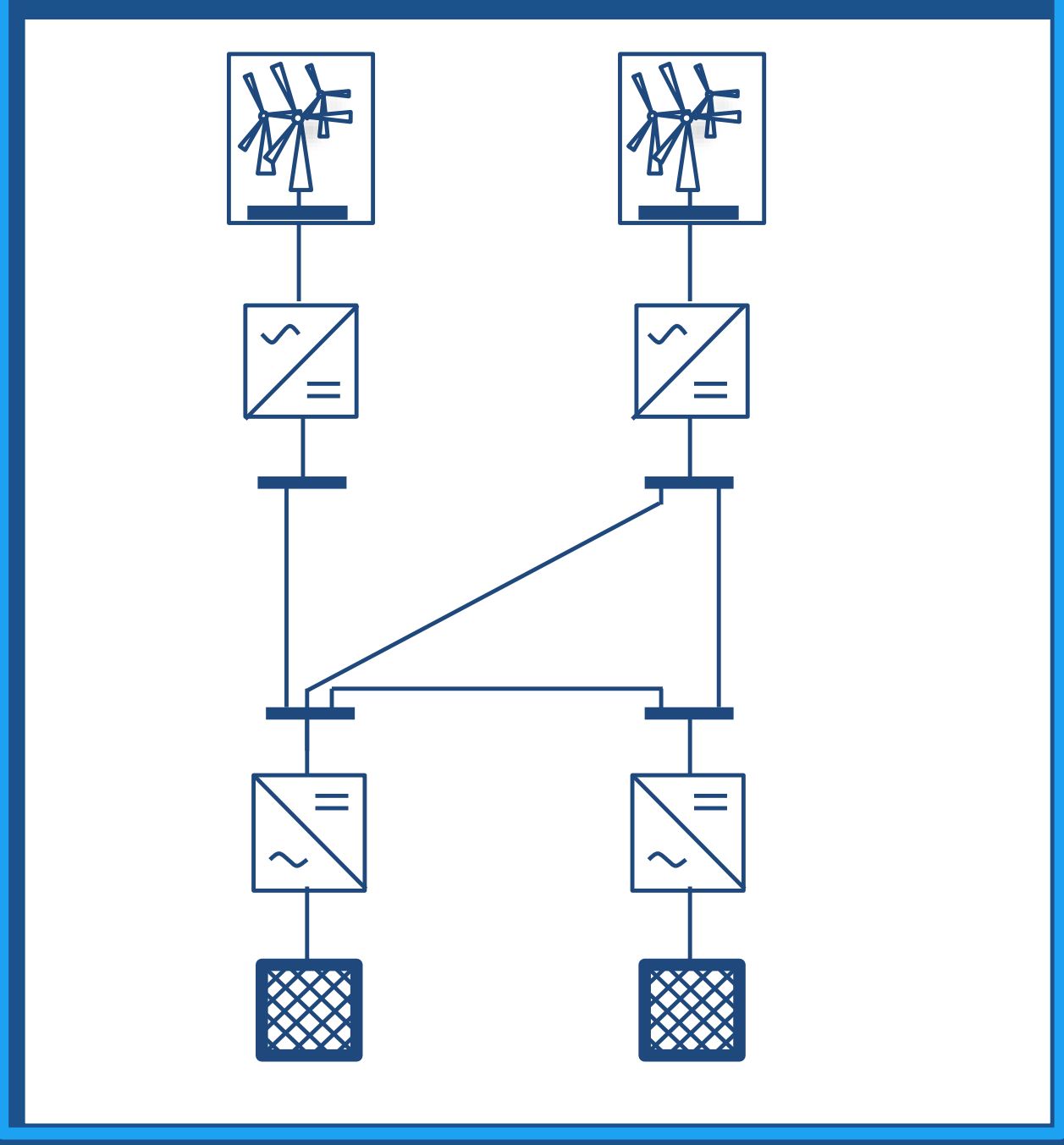
Task 2.1
Definition of model parameters, control objectives and operational assumptions for the meshed HVDC offshore topologies

Task 2.2
Adaption of simulation models for the meshed HVDC offshore topologies

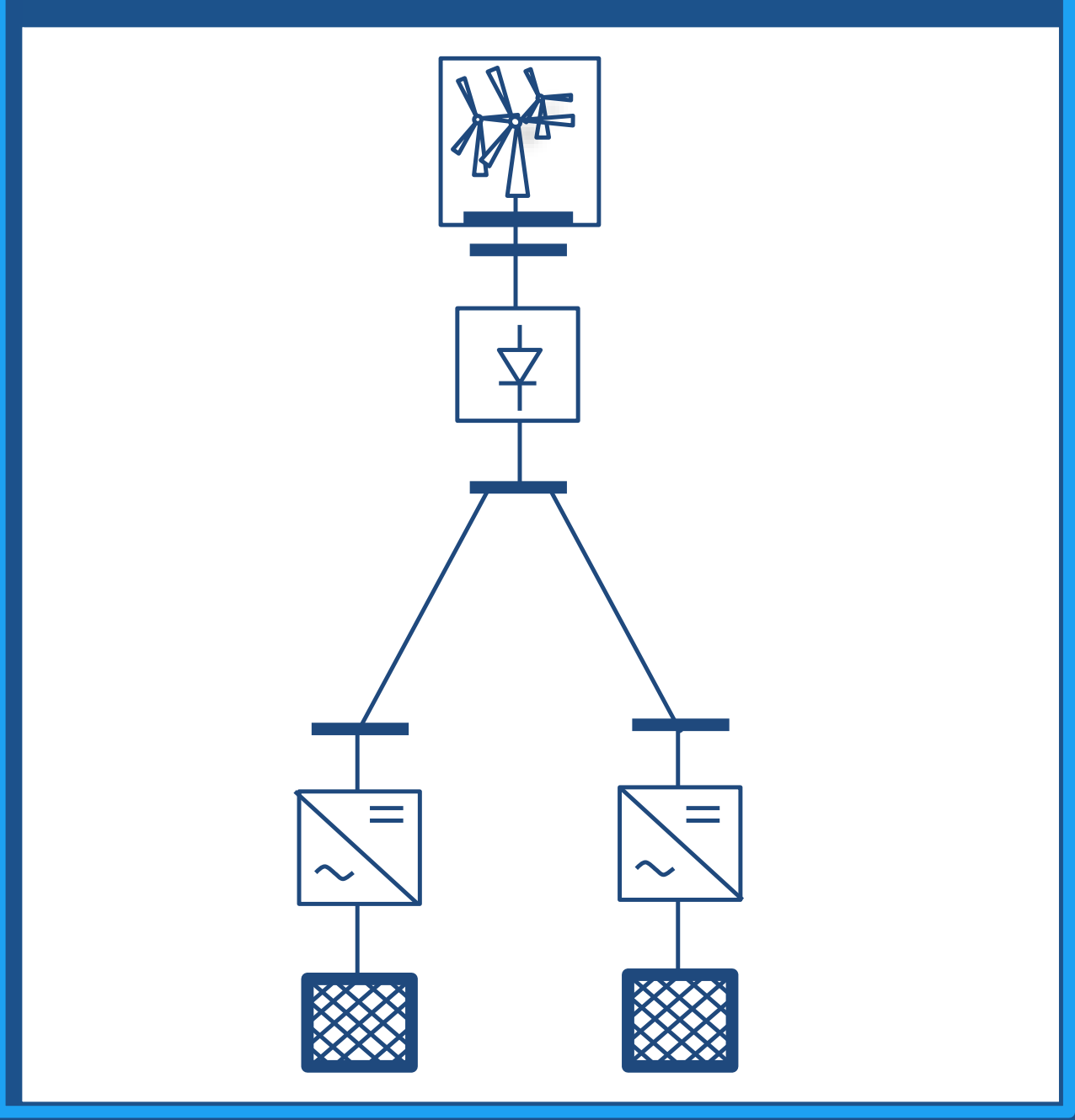
Task 2.3
Simulative investigation and functionality demonstration of the meshed HVDC offshore topology system interoperability

Task 2.4
Define recommendations for minimum requirements on onshore and offshore power systems

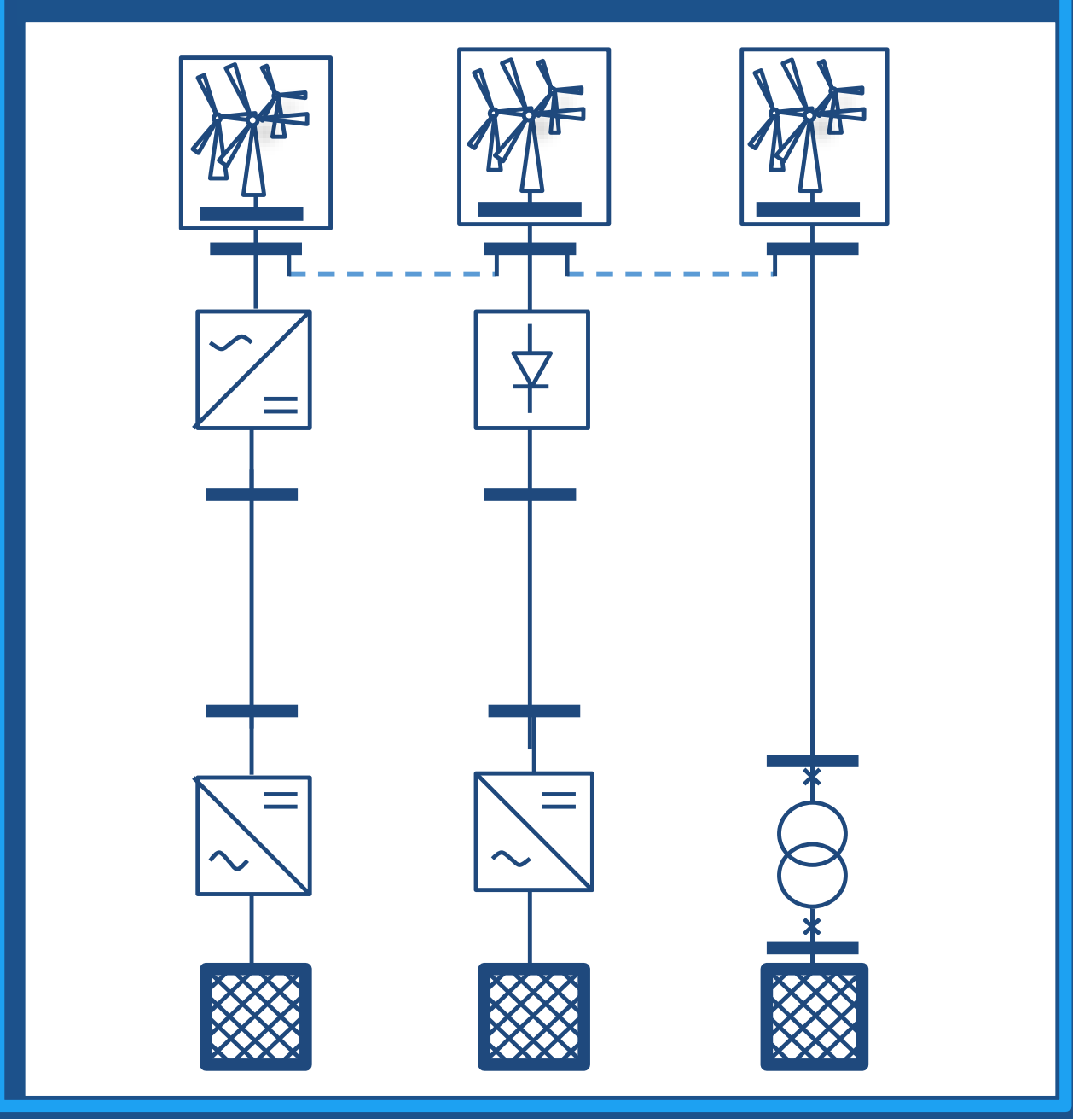
Trade-off analysis of different topologies



Interconnection of VSC and DRC systems



Control concepts to ensure interoperability

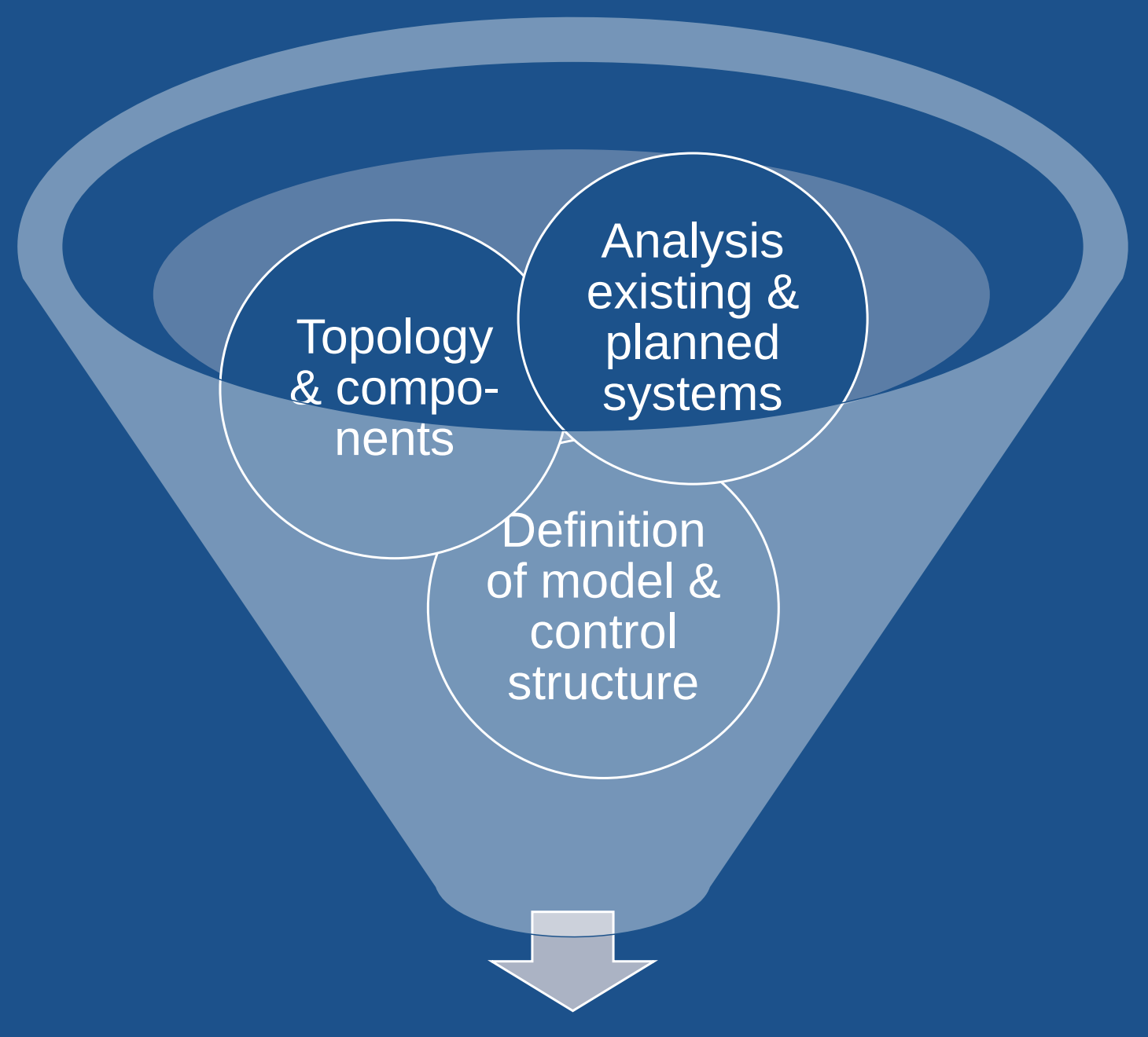


To define recommendations on onshore and offshore power systems for existing grid codes

Broad range of technology and topology options

Framework Definition

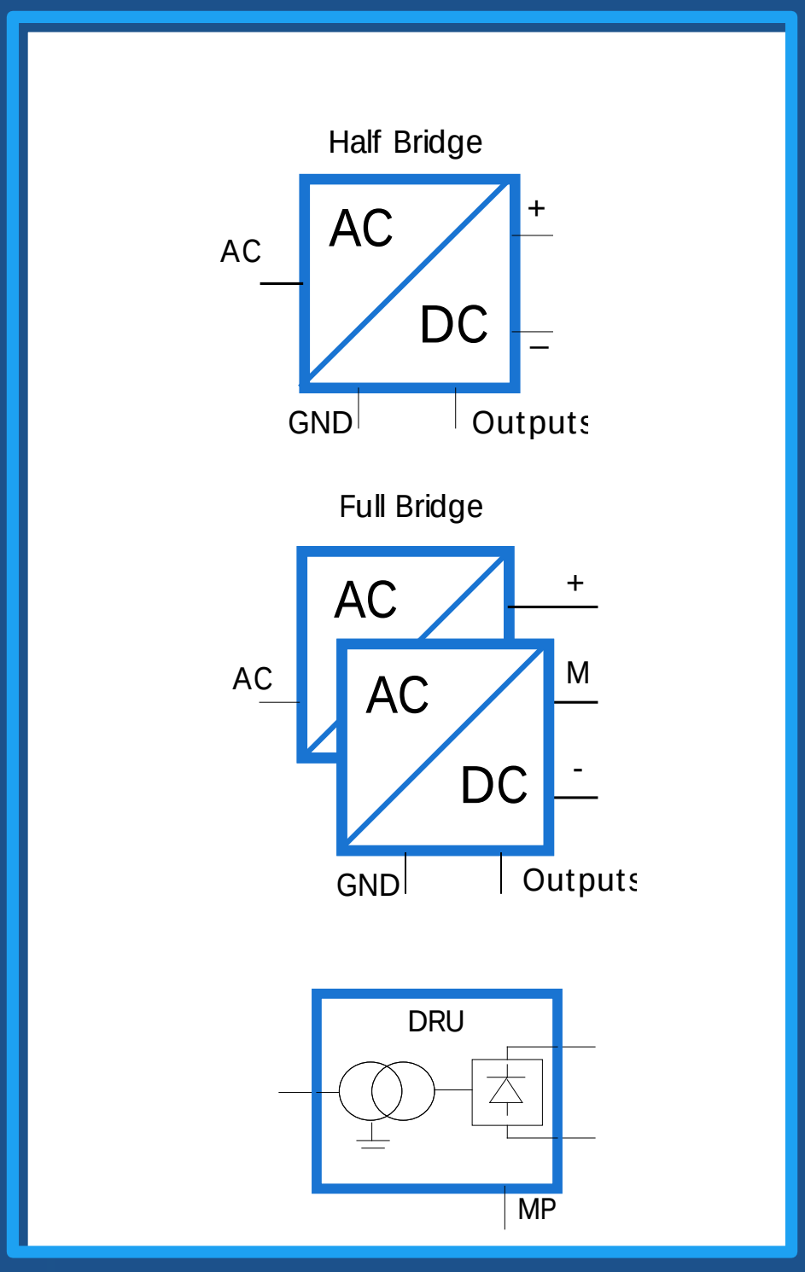
- Multiple technology options for the design of offshore grids and their protection and control
- Investigations in WP2 are based on existing and planned HVDC systems, especially offshore wind farm connections
- Meshed and radial HVDC systems for the integration of offshore wind farms
- Consideration of half-bridge and full-bridge modular multi-level converters and diode rectifier units (DRU)



List of grid topology and model specifications

Model Implementation

- PSCAD model for system analysis under fault conditions based on Cigré model
  - Extension with new converter types and controls
  - DRU integration
- RMS model used to study ancillary services with a focus on frequency support
- Quasi-stationary model for implementing and testing a Security Constrained Optimal Power Flow for interconnected Meshed AC and DC Transmission Systems



PSCAD Converter Model Overview

Interoperability of diode rectifiers (DRU) in multi-terminal HVDC systems

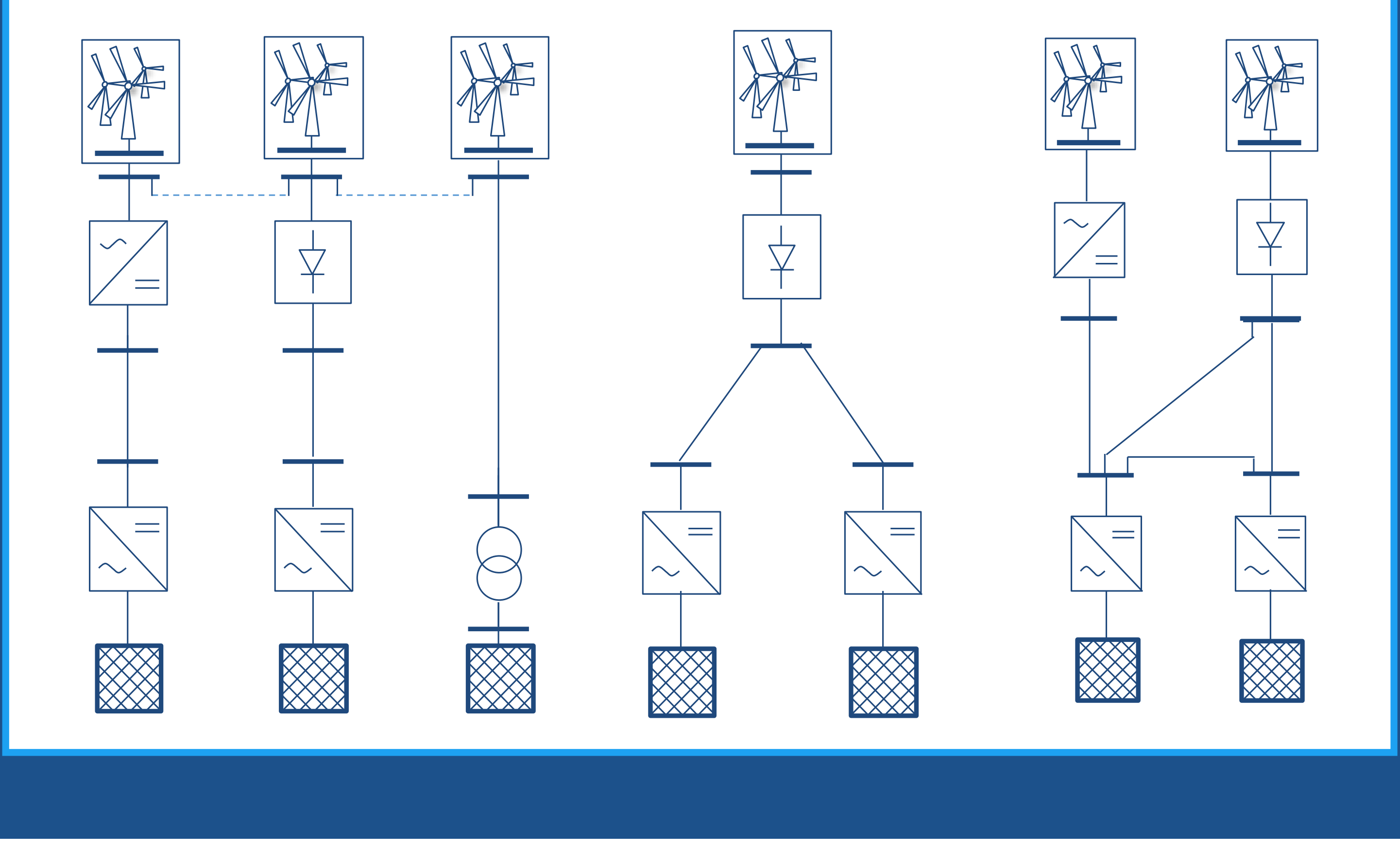
Feasibility of DRU integration into different system topologies

- Diode rectifier unit needs grid forming control for power flow & AC system control: This can be achieved via AC-connected voltage source converters or grid forming wind parks
- The diode rectifier unit itself is based on proven & mature technology

Proof of concept for

- Parallel operation of diode rectifiers with AC link and/or VSC links connected via the AC side has been successfully achieved, taking into consideration required control mode changes for different fault cases and contingencies
  → Parallel operation on the offshore AC side is deemed as a good option to be explored further for HVDC systems in general
- Operation of diode rectifier in combination with grid forming offshore wind parks in multi-terminal and meshed DC grids taking into consideration different fault cases and contingencies

Considered Topologies



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For the WP related deliverables, please refer to:

https://www.promotion-offshore.net/results/deliverables/

For the WP2 related publications, please refer to:

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System operation under contingencies

Combined AC and DC system studies for planning phase

- Phasor modelling of large interconnected AC and DC systems
- Proposition of operational criteria by means of static and dynamic simulations
- Assessment of impact of AC network events on DC networks and vice versa

System analysis in case of contingencies

- Developed SCOPF achieves optimal set points for generation units and converters in interconnected meshed AC and DC transmission systems
- Preventive measures for N-1 contingency situations on DC offshore systems lead to decreased evacuation of offshore wind energy or additional transmission capacity in system (expensive)

→Curative measures in SCOPF for DC offshore systems sufficient

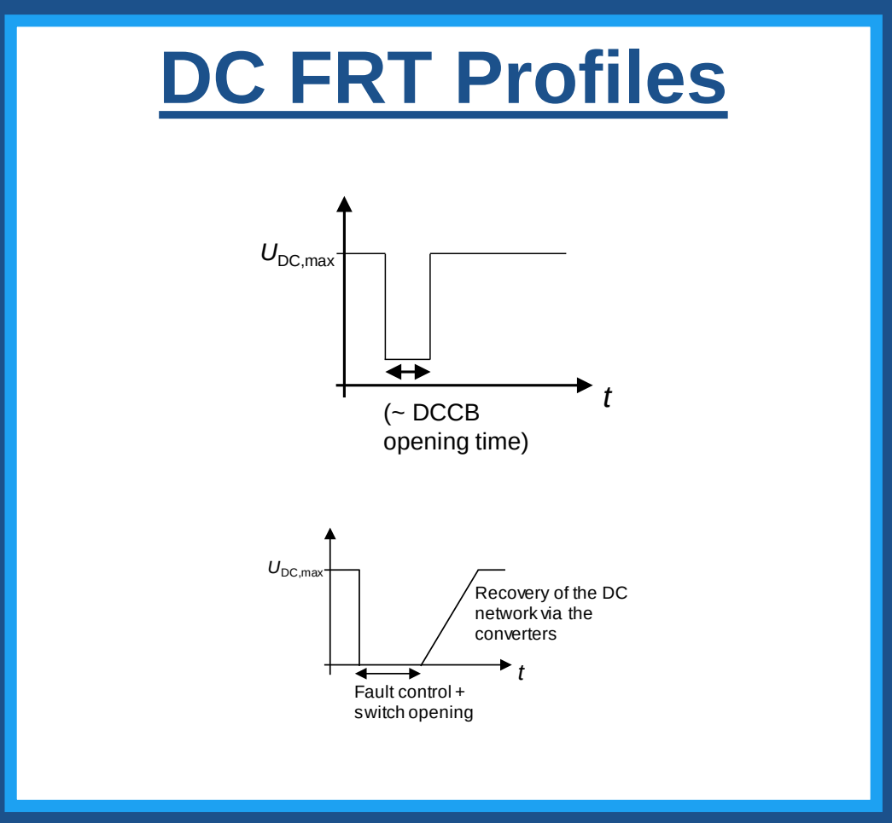
Ancillary service provision – Frequency Support

- Increasing role of HVDC systems and offshore wind power plants leads to increased requirements on them, one example is the contribution to frequency support
- Different options for frequency support were studied
  - From the offshore wind farms
  - From connected asynchronous AC grids
  - Communication-less or communication based
- One major point to consider in the specification of frequency support is the availability of transfer capacity in the HVDC grid for this purpose
- Communication-less approaches are generally feasible, but communication-based approaches are better suited to meet regulatory requirements

System analysis under faults for integration of offshore wind parks

DC System analysis under fault conditions

- HVDC offshore systems integrating a large-scale amount of generation need to robust in case of faults
- The interaction between AC and DC systems was investigated for AC and DC faults and several proposed DC fault clearings strategies
- The interaction between the grid components were analysed to derive requirements on the system operation under faults
- The operation of meshed HVDC systems under a broad range of fault scenarios has been successfully tested



Exemplary DC fault ride through profiles under different DC protection strategies

Interaction with connected wind parks under faults

- While for existing point-to-point offshore wind connections, the offshore wind park will turn off in case of a fault in the HVDC system, they are required to ride through DC faults to allow fast power flow recovery
- The different DC-side fault clearing strategies lead to different requirements on the wind park and its controls, e.g. due to (short-term) blocking of offshore converters or an interruption of power flow transfer. To allow DC-FRT of the wind parks a control concept allowing smooth transition between grid-following and grid-forming of the wind parks was implemented and tested.

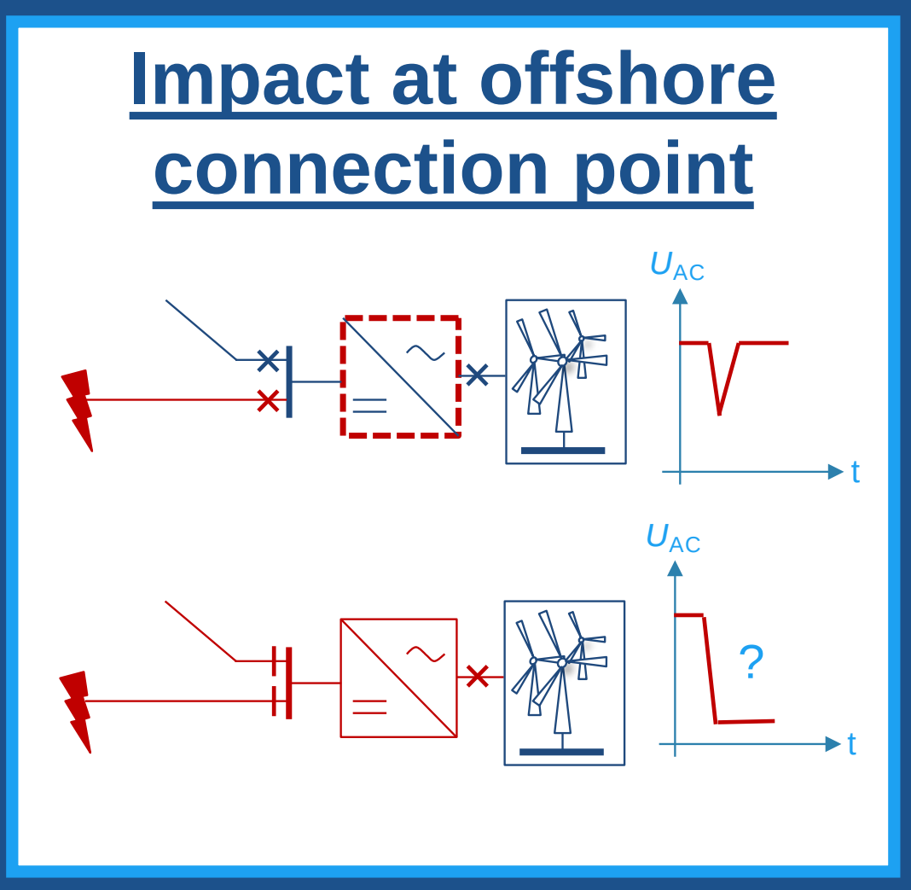


Illustration of exemplary impacts at the connection point of the offshore wind park

HVDC grid codes for future power systems

AC onshore connection point of converters

- Basis: ENTSO-E HVDC Grid Code focuses on the requirements on converters at the AC connection point
- Analysis of selected national implementations, which specify some aspects in more detail
- National implementations seem to converge on some aspects (e.g. AC FRT voltage/time profile), but diverge on others (e.g. accounting for converter capabilities)
- Recommendations:
  - Operational guidelines have to be agreed on between TSOs
  - Behaviour of converters under faults and other transients should be further defined and aligned between TSOs

DC-side grid code

- No DC side grid code specifications available yet
- Challenges:
  - There is no “standard” DC system yet, different system configurations and proposed protection concepts lead to different requirements on the converters and connected equipment
  - Converters have no inherent behavior, the reaction has to be defined in the control system taking into account the limitations of the control and measurement system and the hardware
- Recommendations:
  - To allow a multi-national HVDC grid, (future) HVDC system operators should agree on basic system design aspects, e.g. in a first step on standard DC voltage levels and ranges
  - The specifications of requirements should be done from a system perspective and thereby allowing the use and further development of proposed HVDC technology and control

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