Technical Requirements for Connections to Offshore HVDC grids in the North Sea

Presentation to Grid Connection Stakeholder Committee

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Agenda

- Introduction, challenges and methodology – 5 min

- Companion guide presentation
  - Companion guide chapter 1: connection to onshore AC grid – 10 min
  - Companion guide chapter 2: connection to DC grid – 10 min
  - Companion guide chapter 3: connection to offshore AC grid (“AC hub”) – 5 min

- Conclusion + Q&A - 10 min

01

Introduction, challenges and methodology

Background and scope

The development of **offshore wind is key for meeting carbon neutrality** in Europe by 2050.

The wind potential is estimated to more than 200GW in the North Sea and around 450GW in total in all European seas[1].

It has been shown in many studies that multi-purpose projects (such as evacuation of wind and cross-border interconnectors) can bring **significant cost reductions to the offshore transmission infrastructure**.

In addition to these cost savings, these hybrid projects can be seen as first steps towards the eventual construction of more complex meshed offshore grid structures.

This study focuses on the two following aspects:

- Are there non-harmonized national implementations of the European Connection Network Codes that **would slow down or potentially block** the development of hybrid projects?
- Do the Connection Network Codes cover **technical aspects for connecting a new asset to hybrid projects**?

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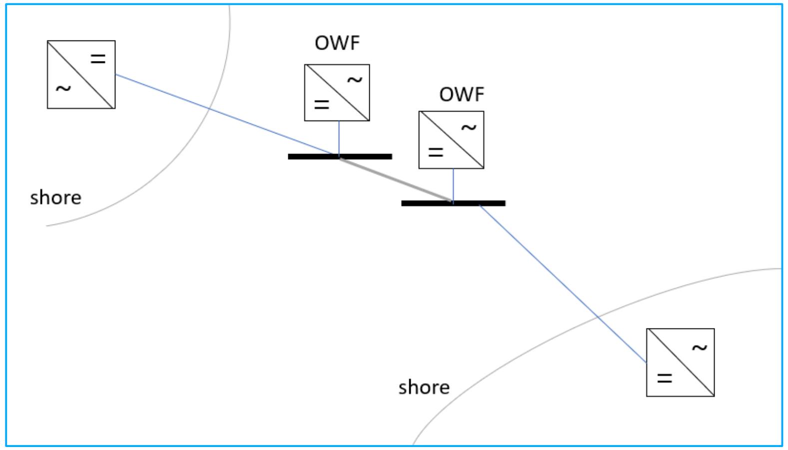
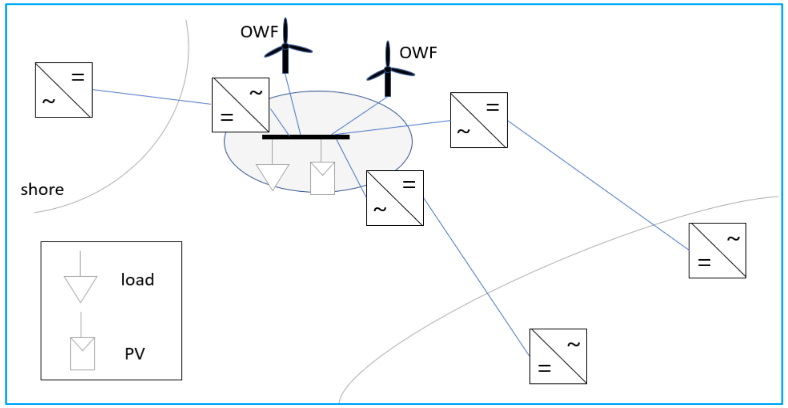
1: WindEurope, https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Our-Energy-Our-Future.pdf

What is a Hybrid Project?

- A Hybrid project refers to offshore transmission infrastructure combining transport of offshore wind energy and cross-border transfer

- This is not a “technical” definition but the fact that hybrid projects are cross-border **results in a higher need for harmonization between national implementations of the NCs**.





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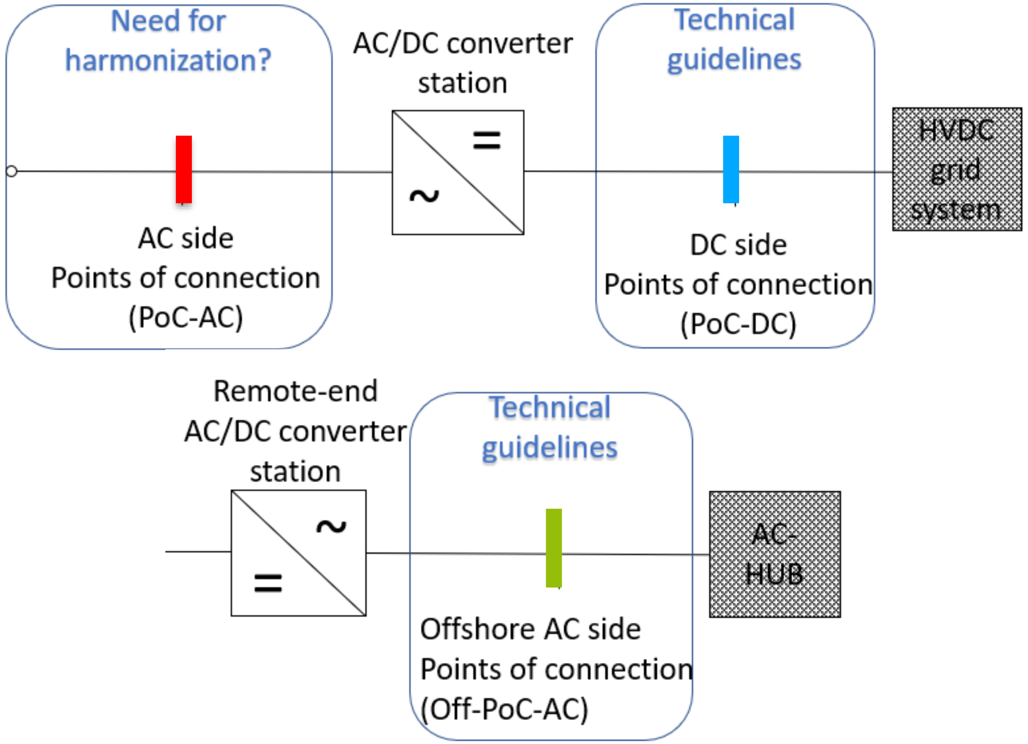
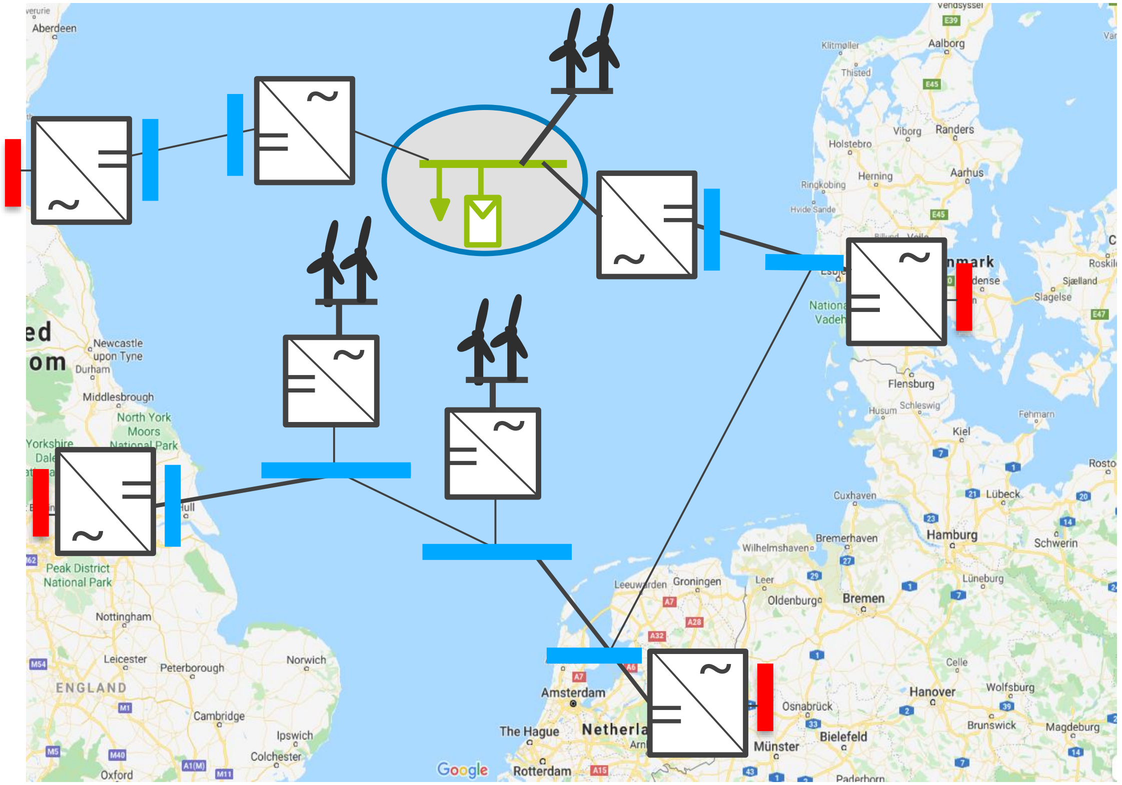
The companion guide contains three main parts

Each of these part analyses challenges/requirements depending on the Point of Connection (PoC)





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Main outcome: our set of recommendation is summarized in a "Companion Guide"

- This **Companion Guide** is a document that:
  - Proposes clarification or extension of the existing requirements of the Network Codes.
  - Complements or suggests additional requirements for hybrid projects.
- There are no strict requirements in this guide but **recommendations**
  - Towards harmonization of specific network code articles
  - Which are a voluntary set of technical guidelines for identified gaps/technical barriers not covered in the existing network codes
  - Which represent the Consultant's opinion after an objective and independent assessment (based on literature review, stakeholder consultation and own expertise in the topic).
- The Companion Guide is **not a binding document**
- Available here: https://ec.europa.eu/energy/studies/technical-requirements-connection-hvdc-grids-north-sea_en

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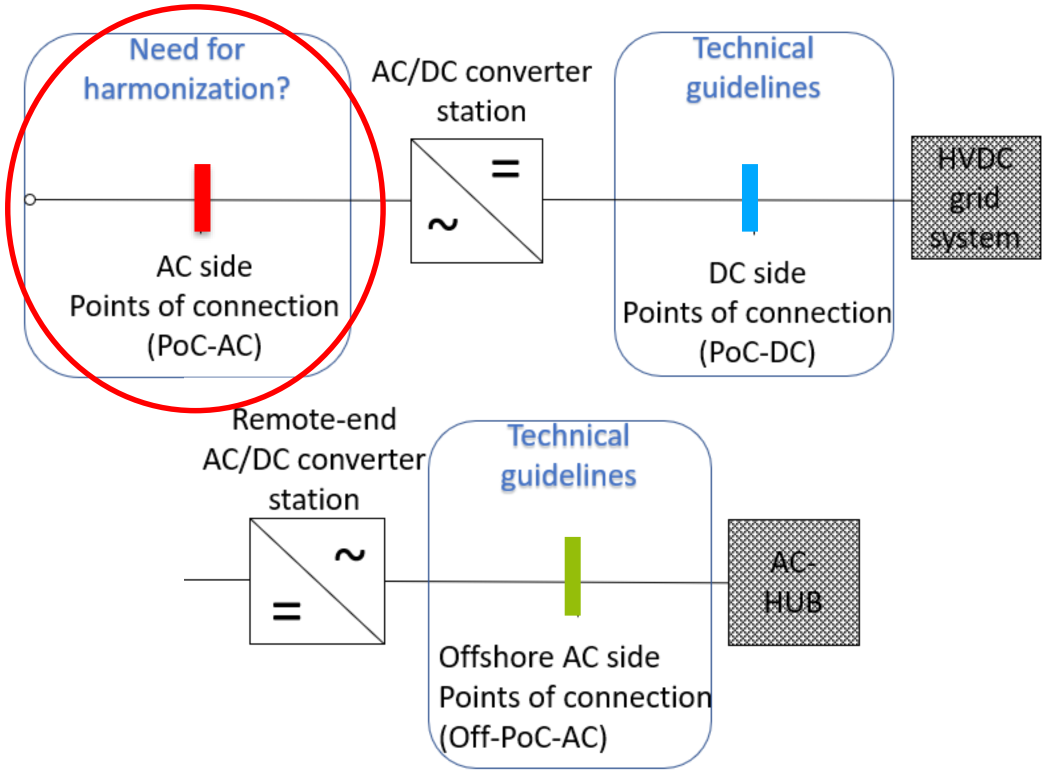
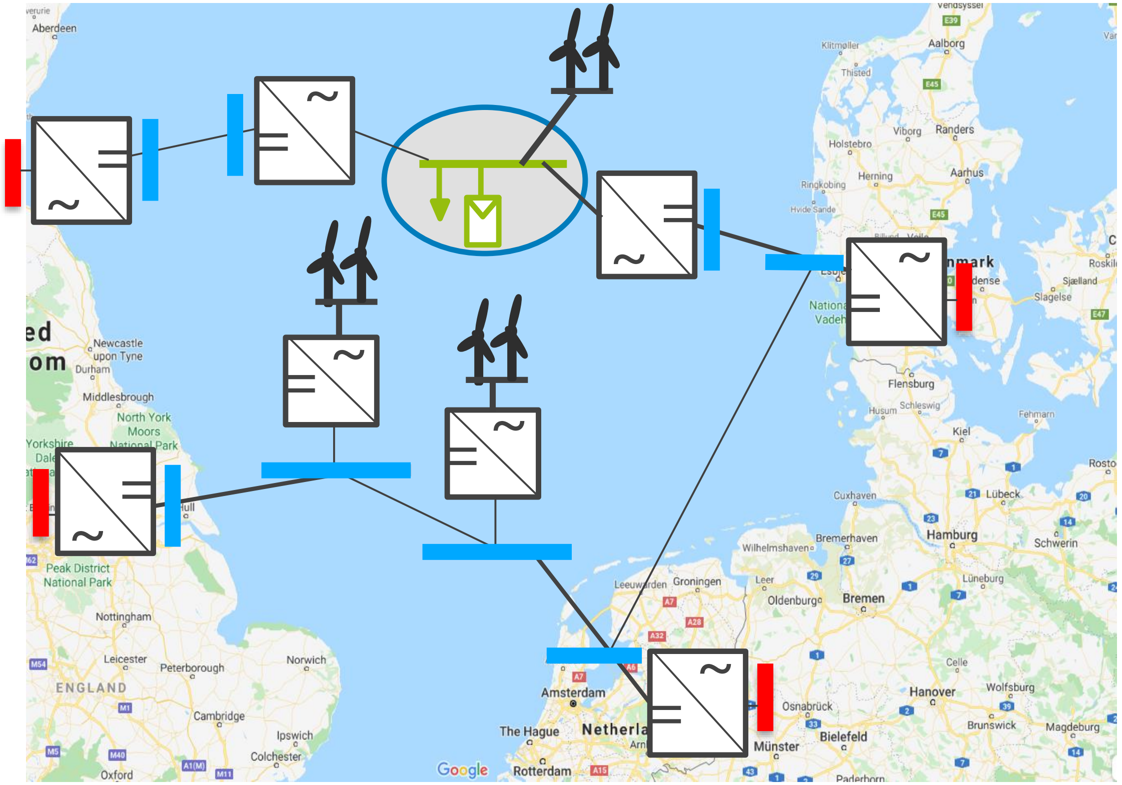
02

Part 1 - Connection to Onshore AC Grids

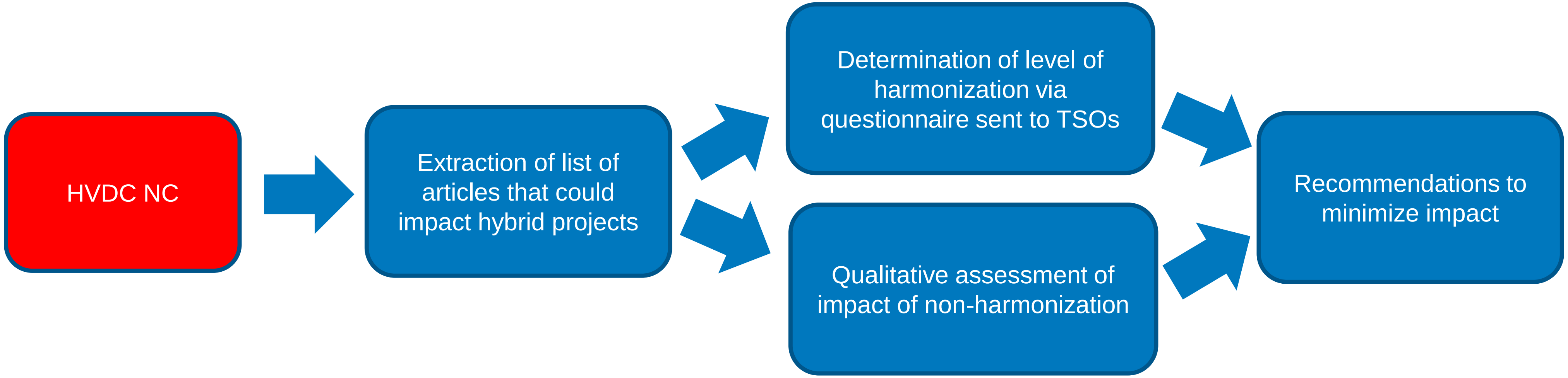
Part 1 focuses on the onshore AC point of connection





The main reference document is the existing HVDC NC

- Technical requirements have been categorized into seven main topics
- HVDC Grid code is sufficiently mature for point-to-point connections
- Less mature for more complex HVDC topologies



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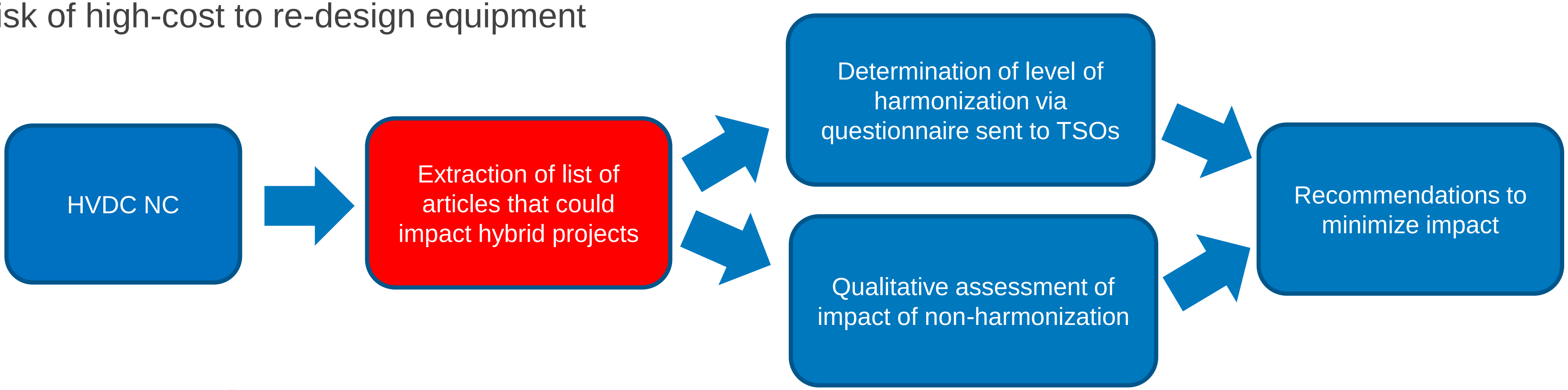
Detailed analysis of the HVDC NC to select articles potentially impacting hybrid projects

- First filtering of articles that could have significant impact on evolution of hybrid projects due to conflicting national variations
  - Requirements that could act as blocking points
  - Risk of non-compliance
  - Risk of high-cost to re-design equipment



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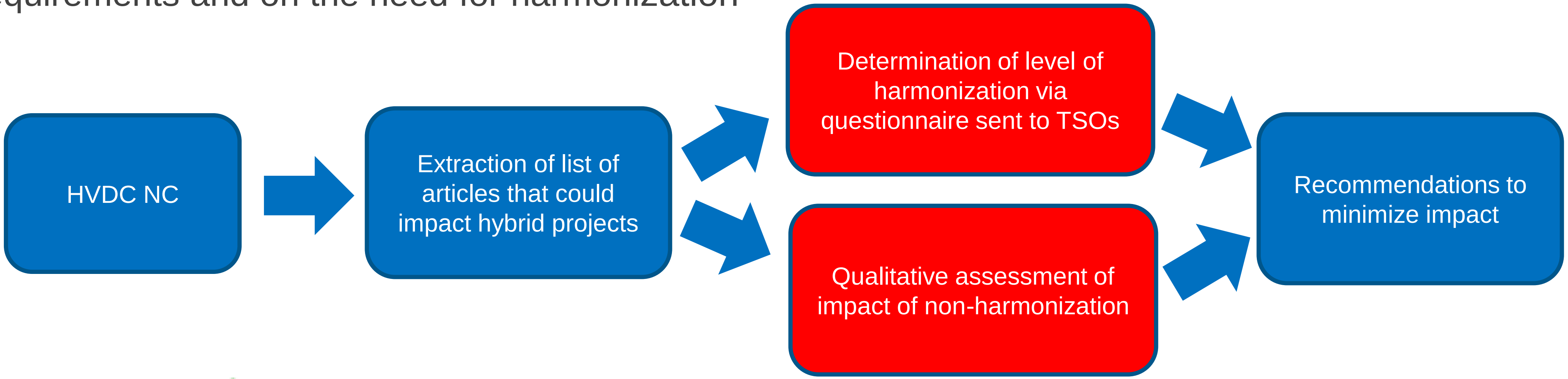
Analysis of the level of convergence and impact of non-harmonization

- Questionnaire sent to TSOs
  — To understand the reasoning behind variations in the national implementations
  — To identify the importance of each article for each TSO
  — To investigate the opinion of each TSO for new requirements and on the need for harmonization
- Qualitative assessment of impact
  — More specific assessment of the impact of non-harmonization
  — Traffic light approach: Impact can be High, Medium or Low



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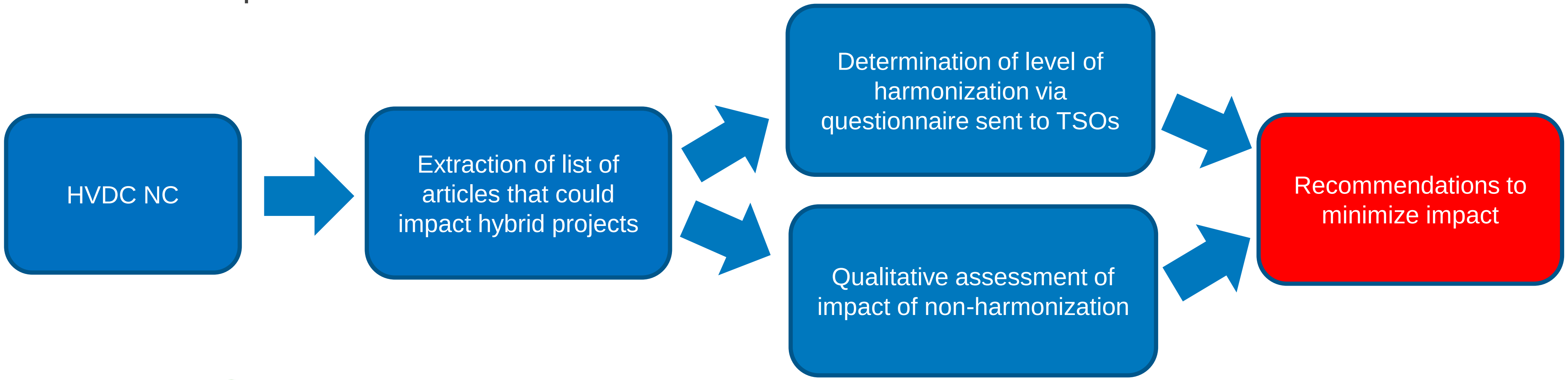
Practical recommendations for each selected article

- For each requirement, a recommendation is provided:
  - Can increased coordination between the TSOs solve any non-harmonization issues?
  - Is harmonization between the TSOs necessary, if possible?
  - Is further operational experience required? What to do till then?
  - Are additional requirements needed?



Articles are grouped in seven topics and color-coded according to their importance for hybrid projects

- Information exchange and coordination
- Protection devices and settings
- Active power control & frequency support
- Fault-ride through capability
- Other control schemes related to AC grid
- Power system restoration
- Reactive power control and voltage support

Red	Non-harmonization could: • Be a blocking point • Lead to significant cost to re-design equipment • Improbable that other solutions exist
Orange	Harmonization not strictly required • Increased coordination between stakeholders required • Harmonized requirements on the DC side could be an option
Green	Non-harmonization not seen as a blocking point, but high coordination is recommended

What our recommendations look like?

- In total 16 recommendations structured as follows:

NC Article No.	Topic	Current Degree of Harmonization	Impact of Non-harmonization	Proposed Action

- Current degree of harmonization gives details on where the variations are observed
- Impact of non-harmonization describes which aspect of a hybrid project is affected
- Proposed actions
  - describe how the impact can be mitigated
  - do not necessarily lead to Network Code amendments

Example 1: Electrical protection schemes and settings

Article 34

Electrical protection schemes and settings

1. The relevant system operator shall specify, in coordination with the relevant TSO, the schemes and settings necessary to protect the network taking into account the characteristics of the HVDC system. Protection schemes relevant for the HVDC system and the network, and settings relevant for the HVDC system, shall be coordinated and agreed between the relevant system operator, the relevant TSO and the HVDC system owner. The protection schemes and settings for internal electrical faults shall be designed so as not to jeopardise the performance of the HVDC system in accordance with this Regulation.

NC Article No.	Topic	Current Harmonization	Impact of Non-harmonization	Proposed Action
34.1	Electrical protection schemes and settings	Project-specific Lack of operational experience makes short-term harmonization and even coordination challenging	High, lack of specific requirements can have significant impact on the design and cost of a hybrid project	More practical experience (e.g. via flagship project) is needed to define more specific requirements. Increased coordination between TSOs until maturity is reached.

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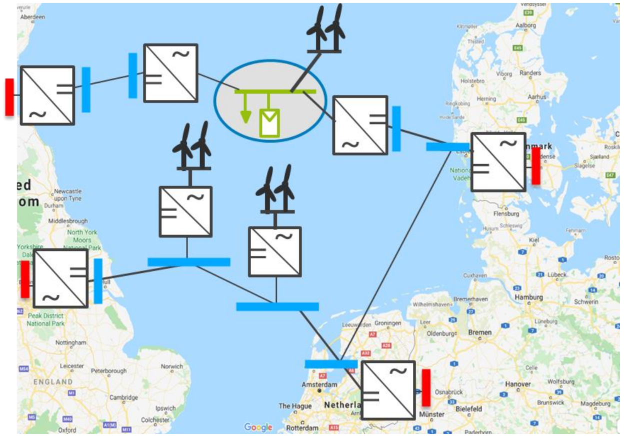
Example 2: Maximum loss of power infeed

Article 17

Maximum loss of active power

1. An HVDC system shall be configured in such a way that its loss of active power injection in a synchronous area shall be limited to a value specified by the relevant TSOs for their respective load frequency control area, based on the HVDC system's impact on the power system.

2. Where an HVDC system connects two or more control areas, the relevant TSOs shall consult each other in order to set a coordinated value of the maximum loss of active power injection as referred to in paragraph 1, taking into account common mode failures.



Converters and DC cables rating directly affected by allowed maximum loss of infeed

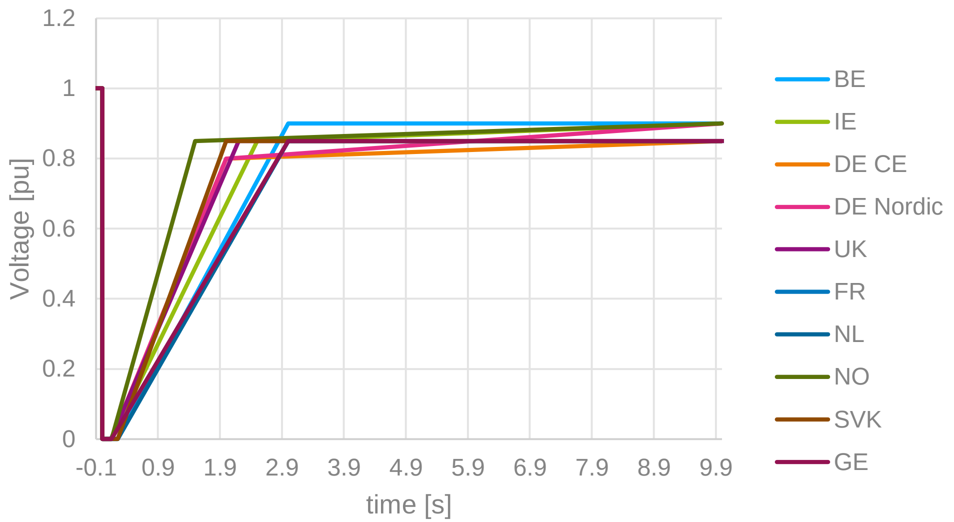
NC Article No.	Topic	Current Degree of Harmonization	Impact of Non-harmonization	Proposed Action
17.1 and 17.2	Maximum Loss of power	National implementations vary, value not explicitly stated in all national implementations. Some TSOs explicitly link it to the Frequency Restoration Reserves (FRR). No mention is made on total maximum system loss.	Medium, will impact the hybrid project design.	Specify the maximum allowed total power loss in each synchronous area to the value of the frequency containment reserve (FCR). Investigate the harmonization of the maximum loss of power in each LFC of the same synchronous area and impact on FRR, considering the dynamics of HVDC grids.

Example 3: Fault ride-through

Article 25

Fault ride through capability

1. The relevant TSO shall specify, while respecting Article 18, a voltage-against time profile as set out in Annex V and having regard to the voltage-against-time-profile specified for power park modules according to Regulation (EU) 2016/631. This profile shall apply at connection points for fault conditions, under which the HVDC converter station shall be capable of staying connected to the network and continuing stable operation after the power system has recovered following fault clearance. The voltage-against-time-profile shall express a lower limit of the actual course of the phase-to-phase voltages on the network voltage level at the connection point during a symmetrical fault, as a function of time before, during and after the fault. Any ride through period beyond t_{rec2} shall be specified by the relevant TSO consistent with Article 18.



NC Article No.	Topic	Current Degree of Harmonization	Impact of Non-harmonization	Proposed Action
25.1	Fault ride-through capability	National variations in LVRT envelopes differ.	Medium, could result in high costs to ensure compatibility of different HVDC systems.	Maintain coordination between TSOs. Definition of harmonized requirements on the DC-side.

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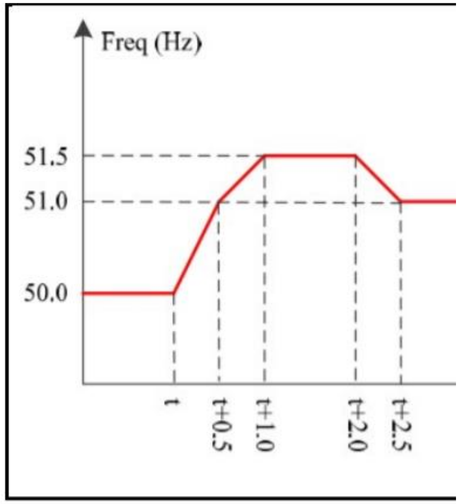
Example 4: Frequency ranges



Over-frequency profile[1]

Article 11

Frequency ranges

1. An HVDC system shall be capable of staying connected to the network and remaining operable within the frequency ranges and time periods specified in Table 1, Annex I for the short circuit power range as specified in Article 32(2).

NC Article No.	Topic	Current Degree of Harmonization	Impact of Non-harmonization	Proposed Action
11.1	Disconnection Ranges	National implementations differ on over-frequency thresholds.	Medium, might cause operational challenges.	Consider harmonization of requirements within same synchronous area towards the most stringent requirements.

1: image from: Elia, PROPOSAL FOR NC RFG REQUIREMENTS OF GENERAL APPLICATION, https://www.febeg.be/sites/default/files/20180423_bga_comments_to_elia_proposal_for_general_requirements_nc_rfg_sh.pdf

Example 5: Automatic remedial actions

Article 13

Active power controllability, control range and ramping rate

3. If specified by a relevant TSO, in coordination with adjacent TSOs, the control functions of an HVDC system shall be capable of taking automatic remedial actions including, but not limited to, stopping the ramping and blocking FSM, LFSM-O, LFSM-U and frequency control. The triggering and blocking criteria shall be specified by relevant TSO and subject to notification to the regulatory authority. The modalities of that notification shall be determined in accordance with the applicable national regulatory framework.

NC Article No.	Topic	Current Degree of Harmonization	Impact of Non-harmonization	Proposed Action
13.3	Automatic remedial actions	Depends on local constraints. Defined on a project to project basis.	Low, can be mitigated by coordination in the design of the secondary DC Grid control.	Maintain coordination between TSOs. Increased coordination should result in integration of the remedial actions in the secondary DC Grid Control.

Key takeaways

- Some existing requirements need to re-considered/harmonized
- Harmonization on the onshore AC side could be avoided in some cases by specifying additional requirements on the DC side
- Coordination between the relevant TSOs is key
- In total, 16 recommendations summarized in Table 5-8 (section 5.9) https://ec.europa.eu/energy/sites/ener/files/companion_guide_ec_template_standalone.pdf

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03

Part 2 - Connection to a DC PoC

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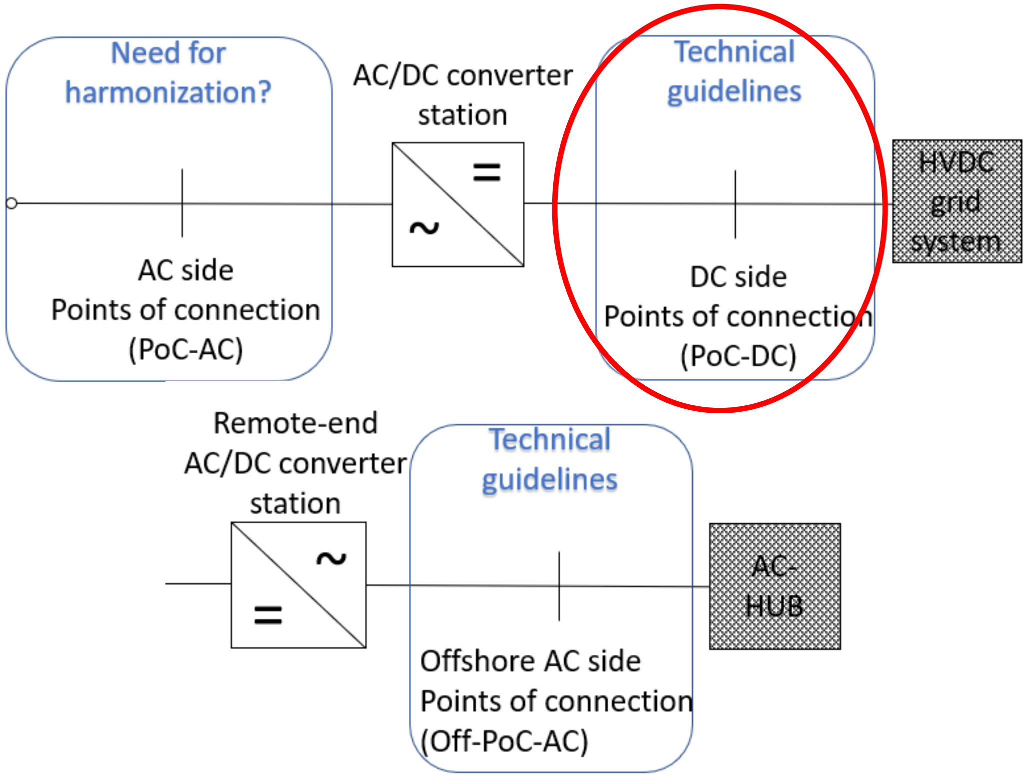
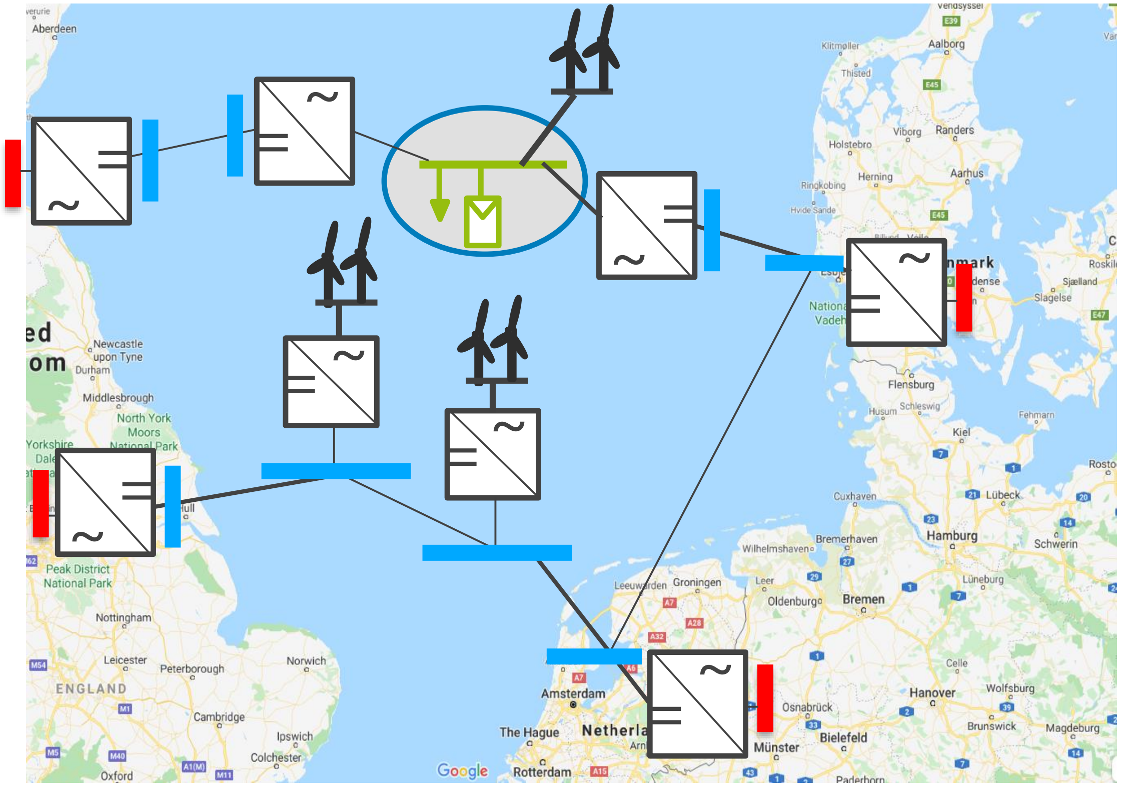
Connection to DC PoC





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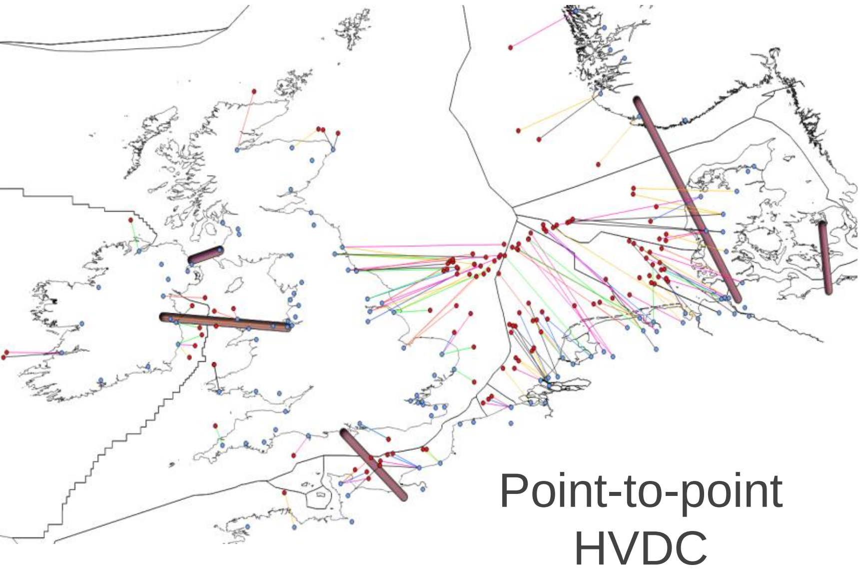
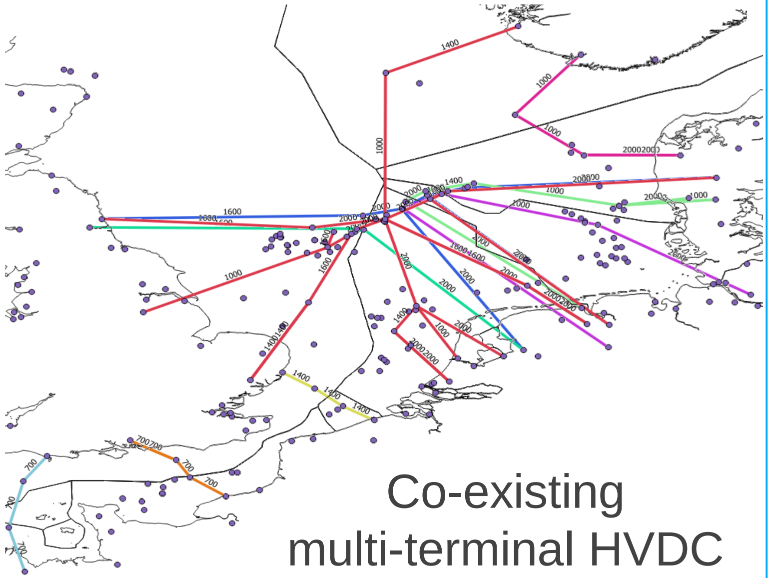
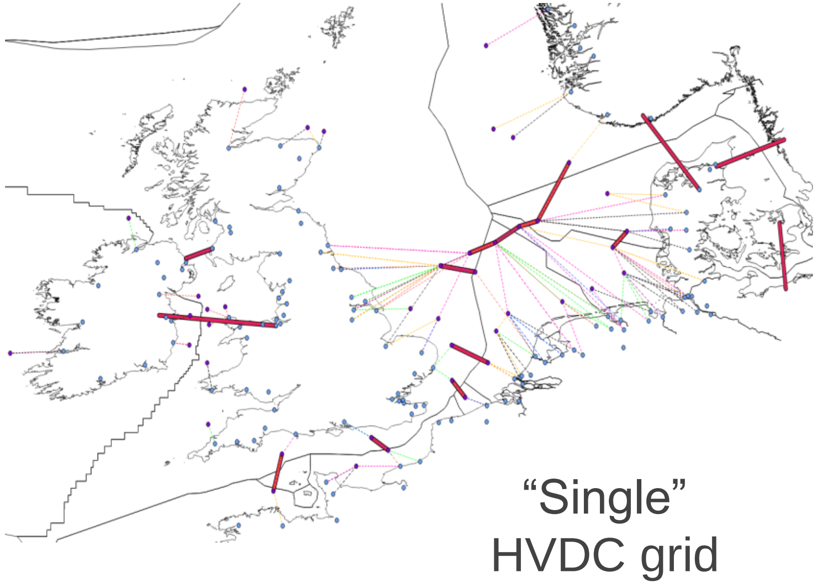
First, let's imagine what could be an offshore HVDC grid in 2050



Point-to-point HVDC



Co-existing multi-terminal HVDC



"Single" HVDC grid

- As-is situation:
  - — Point-to-point HVDC systems
  - — DC side is the responsibility of the HVDC system vendors

→No need for requirements at the DC PoC

- Future situation:
  - — Multi-vendor multi-terminal (meshed) HVDC systems
  - — Optimize use of offshore HVDC grid by allowing non-discriminatory connection at DC terminals

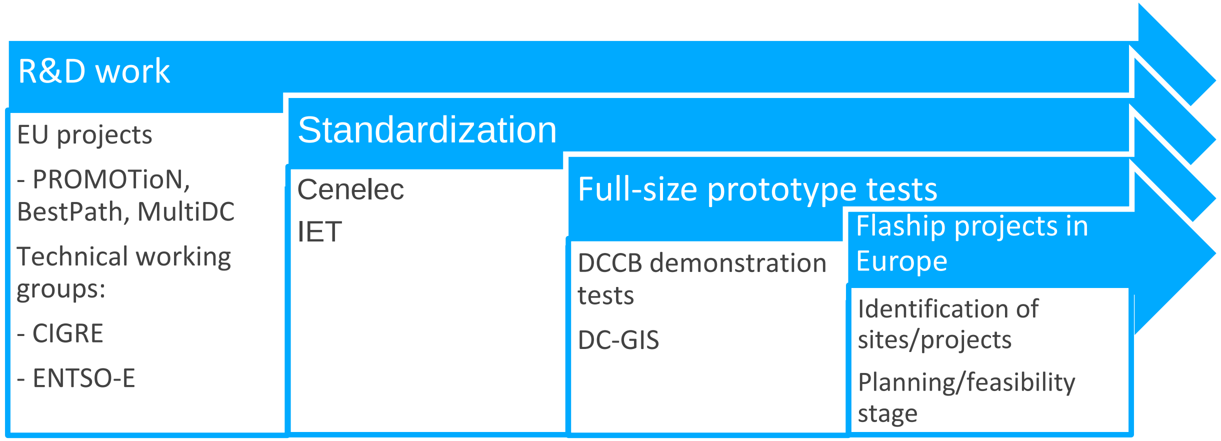
→ Need for requirements at the DC PoC

Figures representing 2050 scenarios from PROMOTioN D12.2: https://www.promotion-offshore.net/fileadmin/PDFs/D12.2_-_Optimal_Scenario_for_the_Development_of_a_Future_European_Offshore_Grid.pdf

Why would a network code for connection to a DC PoC be needed?

Connection on the DC side of a MTDC will shift the responsibility on the DC-side from vendors of P2P HVDC systems to the HVDC system operators (+ potentially HVDC system integrator). However, setting strict requirements in a network code is not recommended for the moment:

1. Requirements should be technology-neutral and technology still evolving

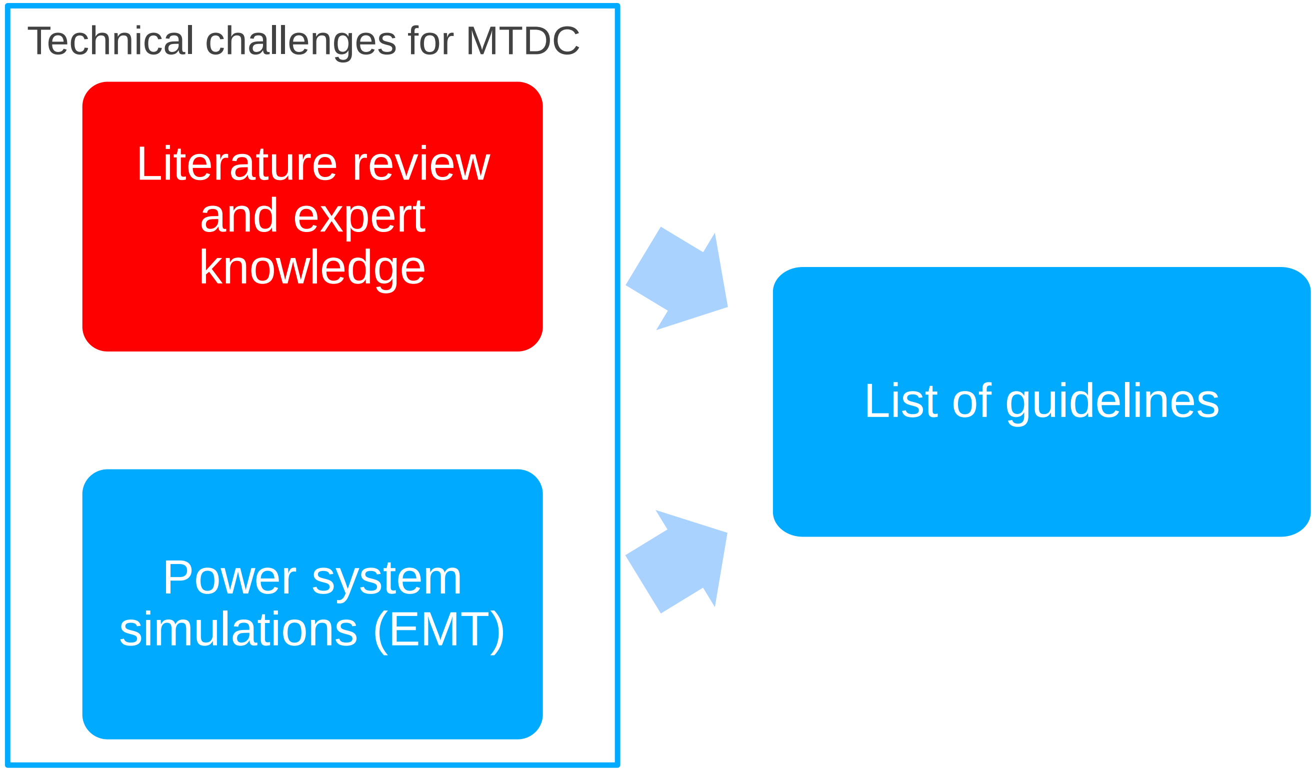


2. First offshore multi-terminal projects in the North Sea are likely to be designed as single dedicated projects (i.e. knowing the exact full and final topology of the system) → **initially coordination of design and functional requirements could be achieved without a network code**

However, grid planning is a difficult task… it is not to be excluded that it will be beneficial in the future to extend or interconnect HVDC systems. At that moment, **a network code for connection to a DC node will most probably be required**.

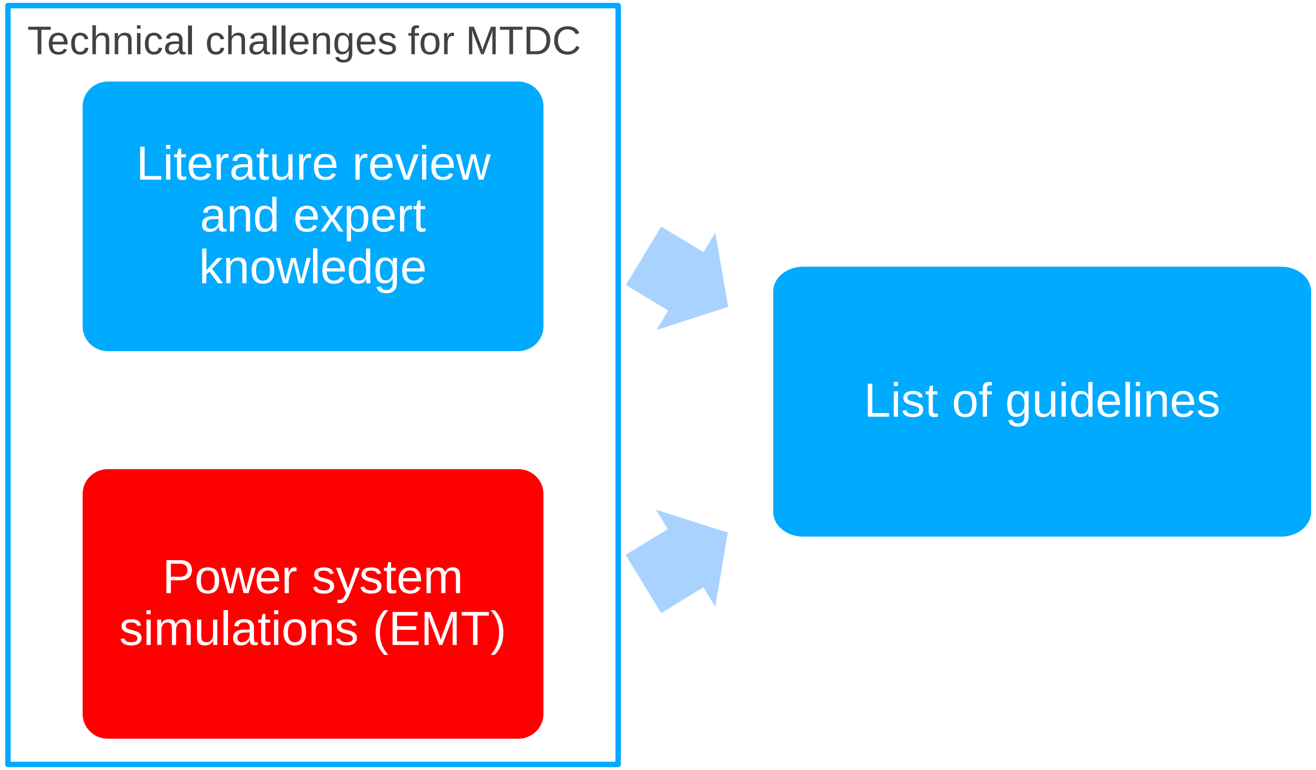
Methodology: literature review as starting point

- Connection network codes do not impose requirements at the PoC-DC.
- The following documents are used as basis:
  - CENELEC standards
  - CIGRE Technical Brochures
  - European projects, such as:
    - PROMOTioN (in particular WP11)
    - BestPath (in particular WP2)
    - MultiDC
  - ENTSO-E papers on:
    - Standardized control interface for HVDC SIL/HIL conformity tests
    - Position on Offshore Development



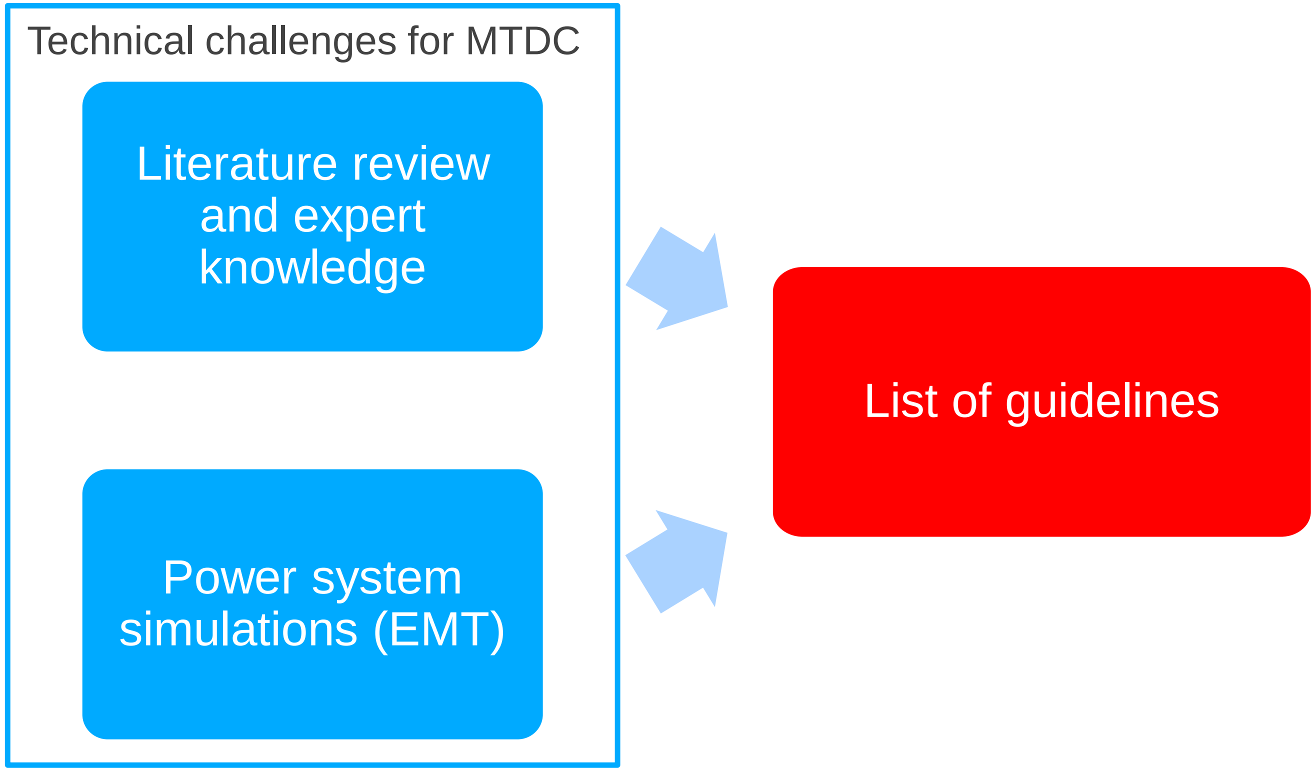
Methodology: use of EMT simulations on a benchmark network

- What is the impact of a new connection on existing assets?
  - Does it require retuning of controls?
  - Does it require redesign or additional costs on existing assets?
  - Is this linked to the protection strategy?
- Goal is to ensure that the HVDC systems stay compliant to connection requirements such as:
  - Maximum loss of power, post-fault active power recovery
  - Adverse interaction, HVDC grid controls, DC Fault-ride through
- Simulations on benchmark network with several HVDC system designs and protection strategies

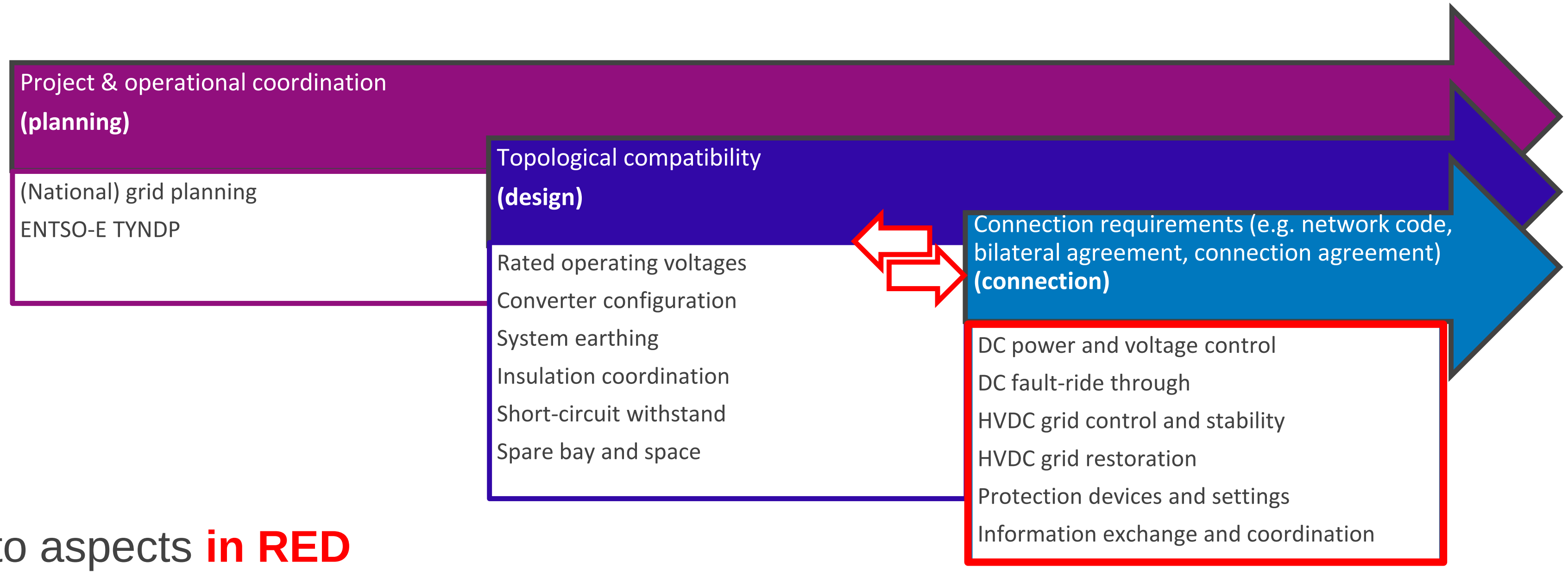


Methodology: main outcome is a list of guidelines

- These guidelines are valid for:
  - Connection to any DC node
  - Any type of HVDC grids (meshed, radial, hubs)
- These guidelines are grouped by categories inspired by the HVDC NC



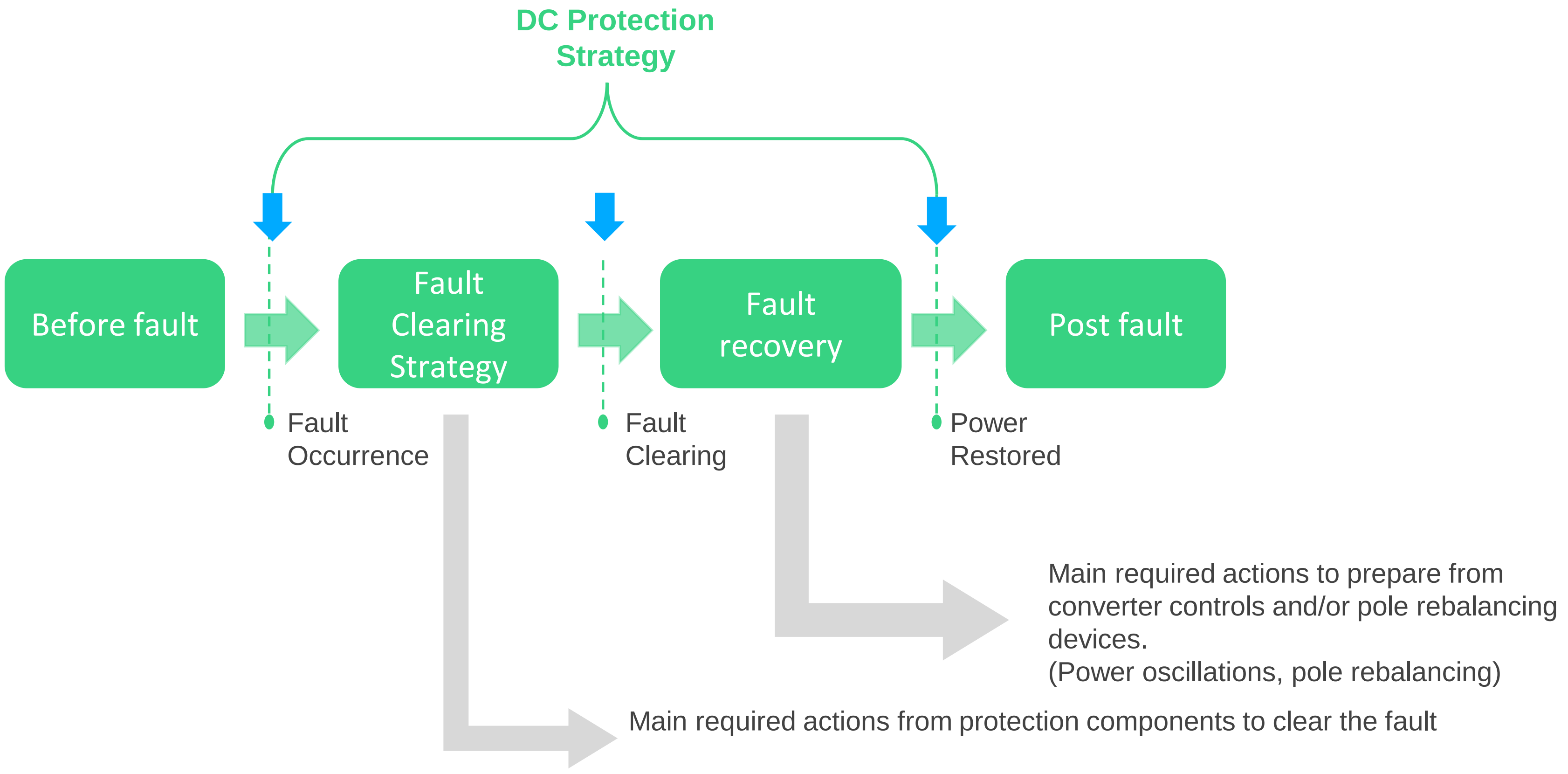
What is covered in the technical guidelines?



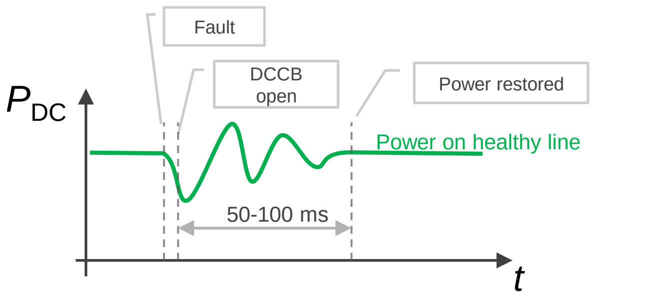
- Scope limited to aspects **in RED**
  - Connection requirements split into 6 categories
  - Can connection requirements be defined independently of the HVDC grid design and protection strategy?
    - More detailed analysis on the DC protection strategy
      - Which aspects have to be coordinated?
      - Which aspects have to be harmonized or be included in a set of common guidelines?

Figure inspired from C. Plet, "Progress On Meshed HVDC Offshore Transmission Networks (PROMOTioN)," InnoGrid, 18 June 2020.

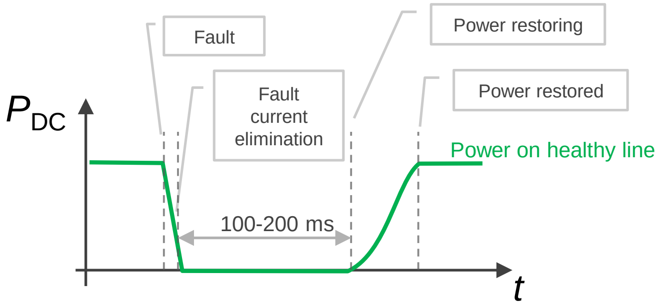
What is meant by DC protection strategy ?



Fully selective fault clearing strategy



Non-selective fault clearing strategy



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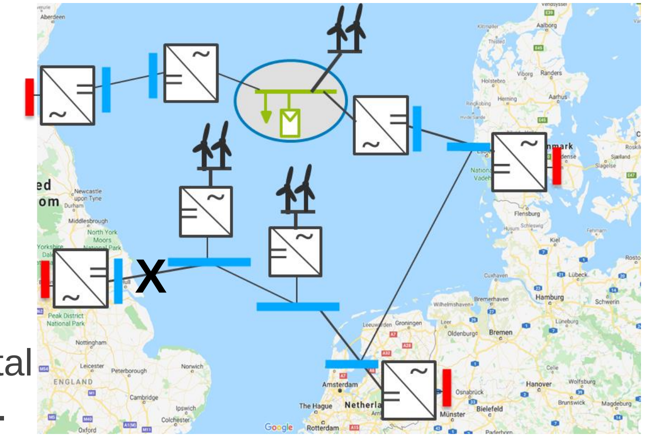
Examples of guidelines: DC power and voltage

Section	Topic	Challenge	Proposed guideline
6.2.1.1	**DC power and voltage**	DC Voltage range	Harmonization of DC voltage ranges would enhance the security of an HVDC grid and (subsequently) the adjacent systems.
6.2.1.3	**DC power and voltage**	DC power quality	Define and harmonize acceptable distortion level in the DC grid.

Examples of guidelines: HVDC grid control and stability

Section	Topic	Challenge	Proposed guideline
6.2.3.2	**HVDC grid control and stability**	Control requirements for remote-end HVDC converters	Control or emergency mechanisms should be developed to coordinate the DC-PPM power adjustment in response to the DC voltage of the remote-end HVDC converter.



Example: if loss of cable to UK, both wind farms will evacuate to Continental Europe. Curtailment might be need to avoid overload of a remaining cable.

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Examples of guidelines:
Protection / Information exchange and coordination

Section	Topic	Challenge	Proposed guideline
6.2.6.2	**Protection devices and settings**	Control interactions	It must be verified that any **new DC grid expansion does not cause adverse interactions with the existing assets**. Standardization on the methodology to study such interactions studies is required.
6.2.6.3	**Information exchange and coordination**	Simulation models	It is recommended that the **TSOs harmonize the required types of simulation models** and expected level of detail through the publication of **a common modelling guideline for HVDC systems**. Compared to PoC-AC, **an agreed framework on the use of replicas** might be even more important to identify DC-side problems when considering extension to more complex HVDC topologies.

Key takeaways

- Connection to the DC side of an HVDC systems is a significant change from existing P2P HVDC systems
- High level of coordination is recommended on the design and planning
- Technical requirements at the DC PoC are likely to be required in the future (via upgrade or new network code), but further practical experience is recommended
- “Fit-and-forget” approach might not be sufficient for HVDC systems. Compliance simulations should be performed through the lifetime of the HVDC system, especially after integration of new equipment or topology adjustments.

- A set of 15 guidelines summarized in section 6.3 of the Companion Guide (https://ec.europa.eu/energy/sites/ener/files/companion_guide_ec_template_standalone.pdf)
- These technical guidelines at the PoC DC that:
  - Could serve as basis for detailed project-specific functional requirements until maturity is reached
  - Could serve as input for a future network code focusing on the DC side (in a later stage)

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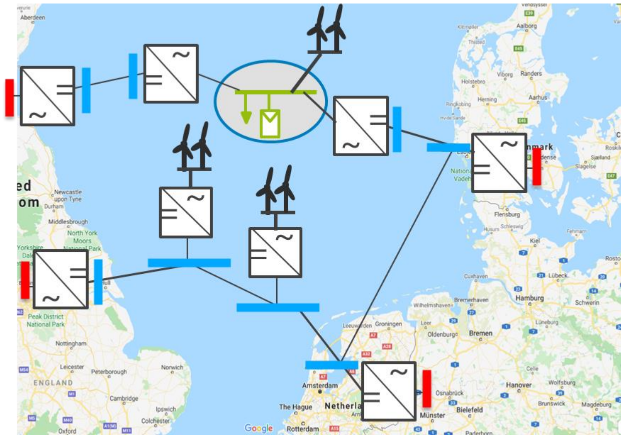
04

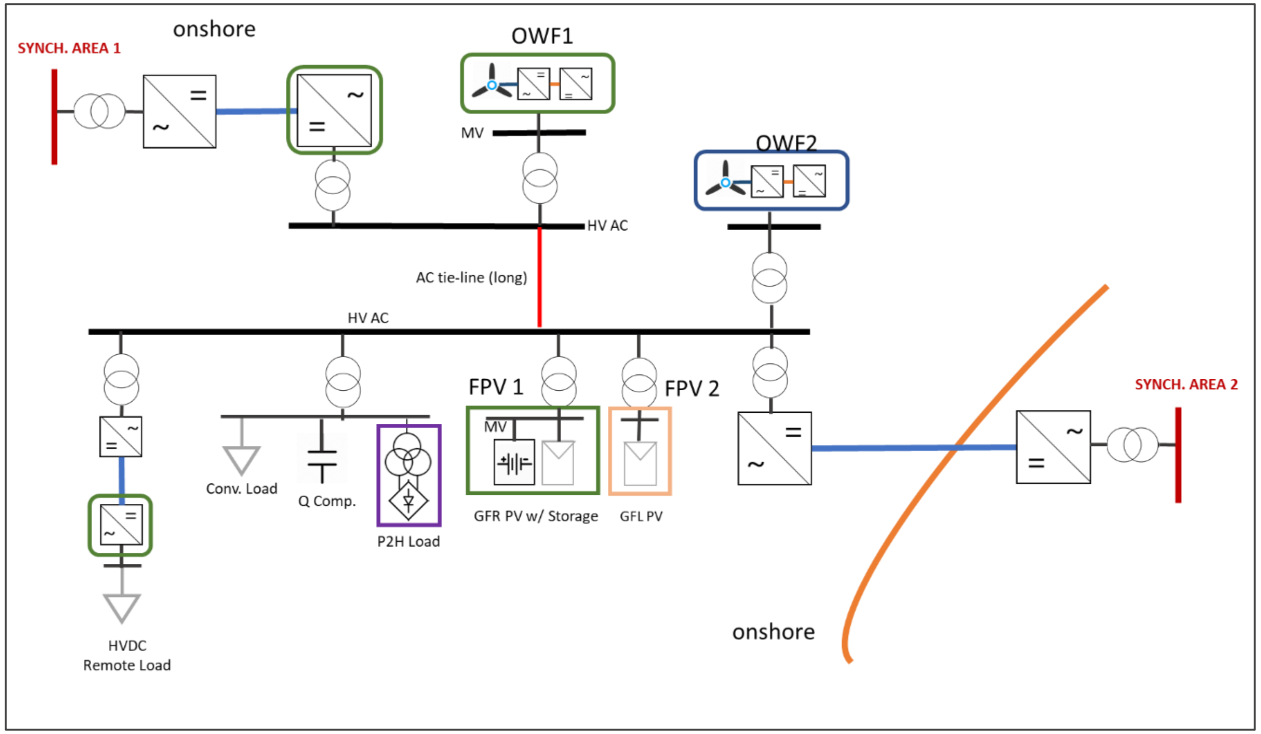
Part 3 - Connection to Offshore AC Grids

AC hubs Structure and Relevancy

Interconnecting offshore wind, storage and loads



- Offshore islanded AC grids with generation and load assets.
  - Up to 15 [GW]
  - Offshore wind power plants
  - Floating PV or storage
  - Loads (e.g. Green H_2)
- Enabled by HVDC interconnections
- Multiple stakeholders involved

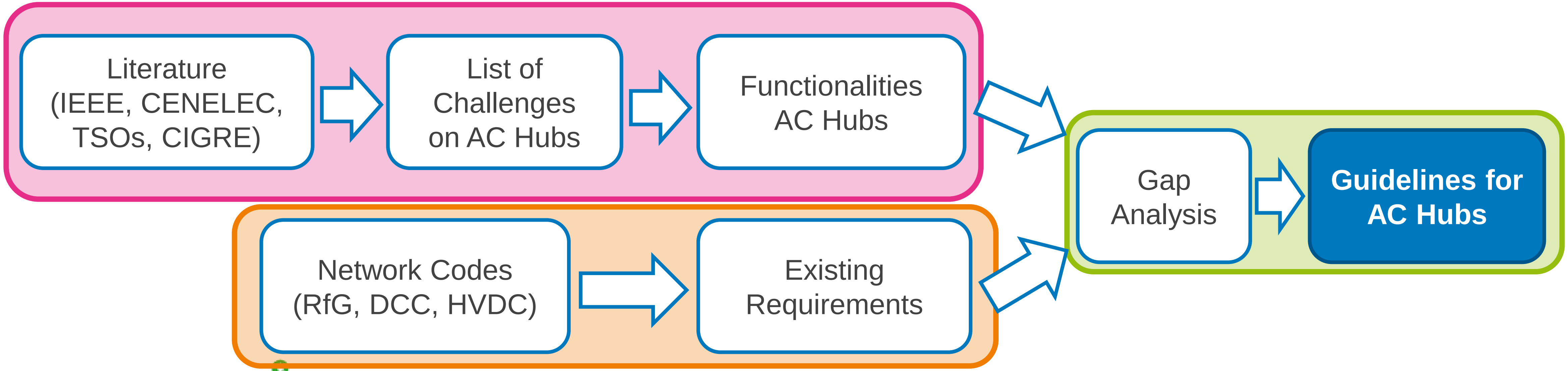


Characteristics of AC hubs
Status and Challenges

- AC hubs still very **immature** and remain research topic
  - **limited** practical experience (microgrids)
- AC hubs have similar operational challenges to large AC systems with High Penetration of Power Electronics Interfaced Power Systems
  - Solutions likely to move towards **Grid Forming Converters** but Synchronous Machines are not to be excluded
- **Complex coordination** is required:
  - Not greenfield asset – staged development
  - Multi-vendor / Multi-owner / Multi-purpose asset
  - Conflicting objectives between AC hub stakeholders

Methodology

- CNCs are not specifically designed for islanded systems. They could cover to some extent AC hubs needs but gaps still exist, and direct applicability is not recommended (different challenges)
- Identification of the challenges of an AC Offshore Hub in comparison with a Synchronous Area
- Gap analysis between.
  - the existing European connection network codes and,
  - the specific needs derived from the specific challenges for offshore AC hubs



10 Key Challenges for AC Hubs

Based on Industry Challenges for HPo PEIPS

- Forming the Voltage
- System Strength
- Adverse System Interaction
- Inertia and RoCoF
- Disturbance Ride-through
- Power Balancing during contingency
- Protection System Impact
- System Restoration
- Simulation Models
- Participation and Coordination

Key Takeaways

- Stability of AC hub will be challenging
- AC hubs will experience similar challenges than systems with High Penetration of PEIPS
- RfGs and DCC are made for Large AC systems (Synchronous Machine Paradigm)
- Coordination between Grid Forming and Grid Following will be essential
- Dynamics and Stability mostly determined by controls

- Practical experience is needed to define clear requirements
- Build on top of the existing research on HPoPEIPS
- Think out of the box and use the entire capabilities of the PPMs.
- Allow new ways of controlling frequency and voltage

Agenda

- Introduction, challenges and methodology – 5 min
- Companion guide presentation
  - Companion guide chapter 1: connection to onshore AC grid – 10 min
  - Companion guide chapter 2: connection to DC grid – 10 min
  - Companion guide chapter 3: connection to offshore AC grid (“AC hub”) – 5 min
- Closure of the workshop – Q&A 10 min

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Conclusions

Main outcome: our set of recommendation is summarized in a "Companion Guide"

- This **Companion Guide** is a document that:
  - Proposes clarification or extension of the existing requirements of the Network Codes.
  - Complements or suggests additional requirements for hybrid projects.
- There are no strict requirements in this guide but **recommendations**
  - Towards harmonization of specific network code articles
  - Which are a voluntary set of technical guidelines for identified gaps/technical barriers not covered in the existing network codes
  - Which represent the Consultant's opinion after an objective and independent assessment (based on literature review, stakeholder consultation and own expertise in the topic).
- The Companion Guide is **not a binding document**
- Available here: https://ec.europa.eu/energy/studies/technical-requirements-connection-hvdc-grids-north-sea_en

Each part has a different motivation, level of maturity and recommendations

	Connection to onshore AC grid	Connection to DC grid	Connection to offshore AC grid
Motivation for analyzing the need of an (updated) network code	Non-harmonization might impact hybrid projects	Not strictly needed now (if Hybrid Projects designed as a coordinated single projects) But will be needed for future extensions or interconnections.	Direct application of existing RfG, HVDC and DCC NC might not be suitable for offshore AC grid
Point of Connection	Onshore AC	Offshore DC	Offshore AC
Intended Public	TSOs / ACER / ENTSO-E (in consultation with other stakeholders)	TSOs / Manufacturers (in consultation with other stakeholders)	TSOs / Manufacturers (in consultation with other stakeholder)
Maturity of the Technology / Application	Vast experience with point-to-point HVDC	Medium – Some MTDC VSC in operation outside Europe, and in feasibility or planning in Europe.	Low – AC hubs are still a research topic.
Maturity of the Requirements	Requirements in place via HVDC NC	Medium – ongoing works on standardization, interoperability, etc.	No requirements exist. CNCs cannot be applied in a straightforward manner.
Type of Recommendations	Specific actions for selected network code articles	Technical Guidelines	Technical Guidelines
Geographical scope	Analysis performed for the North Sea's countries	Not restricted	Not restricted

Thank you for your attention

Any questions: olivier.antoine@engie.com

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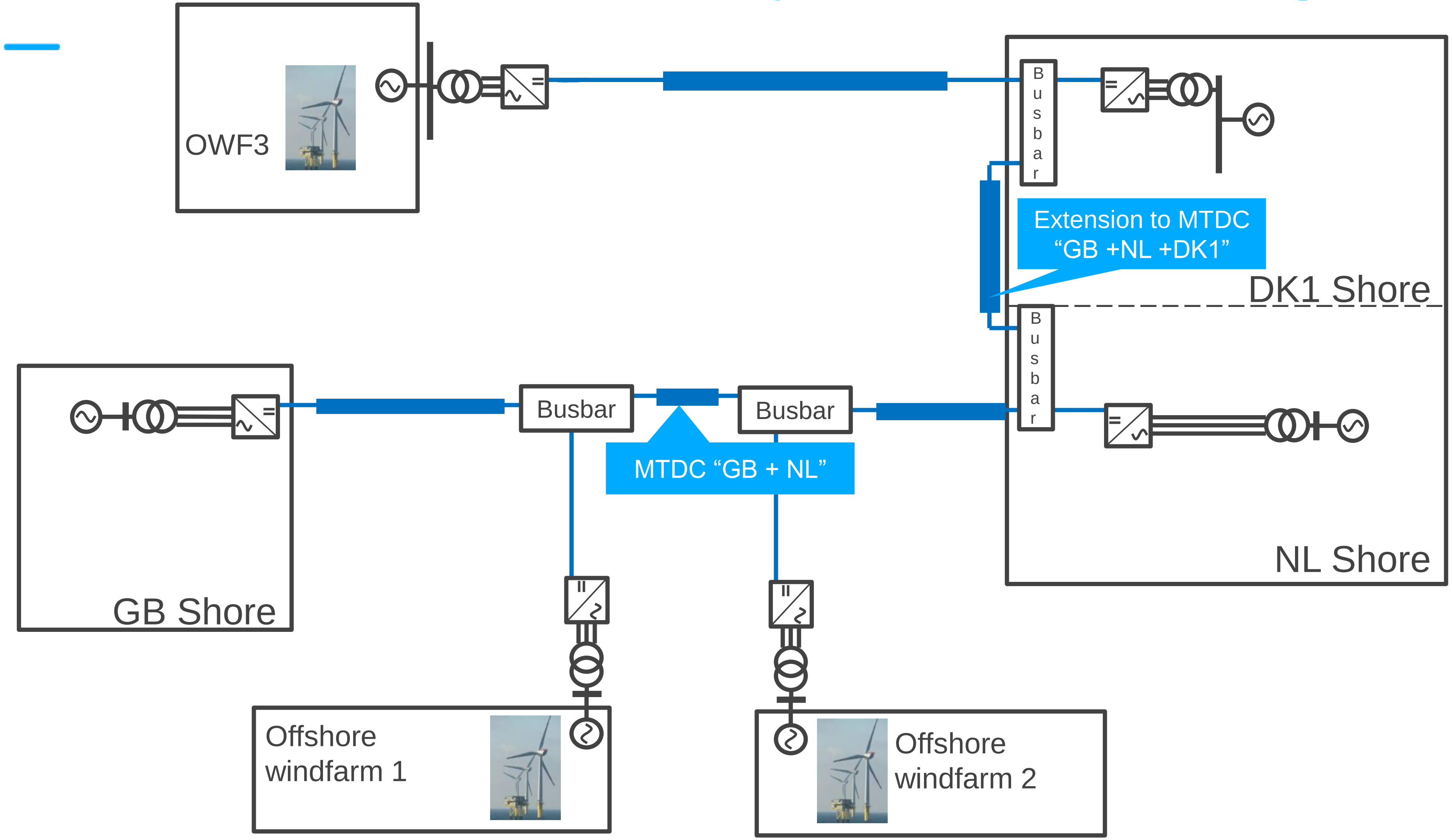
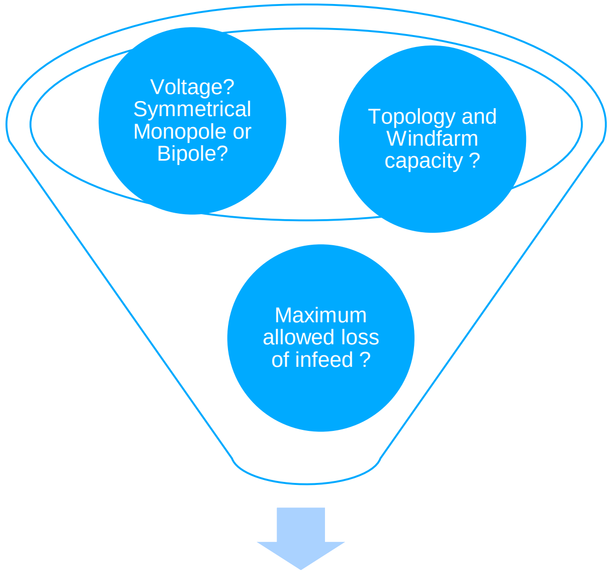
Benchmark network for symmetrical Monopole





Benchmark network configuration
e.g. Bipole with MR
or Rigid Bipole or Symmetric Monopole

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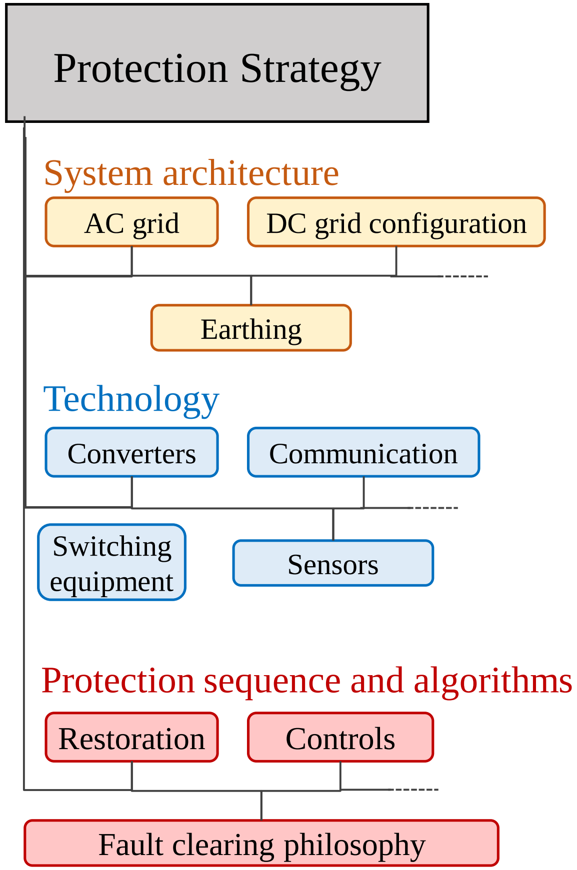
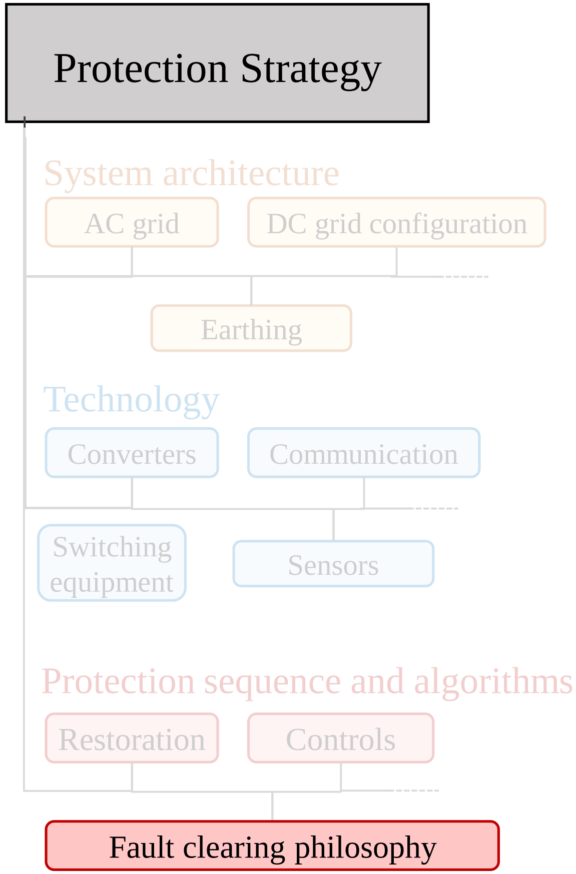
Protection strategy can be considered as a combination of three main elements

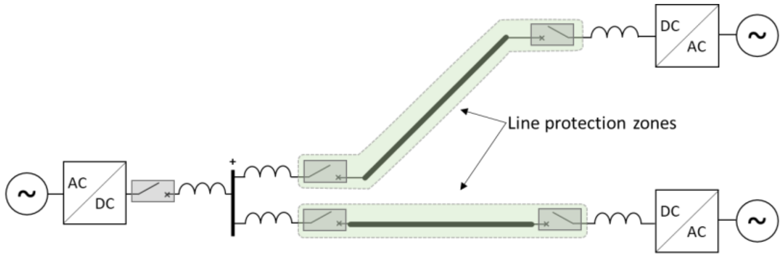


What are the impacts of the protection strategy elements on the DC grid extension ?

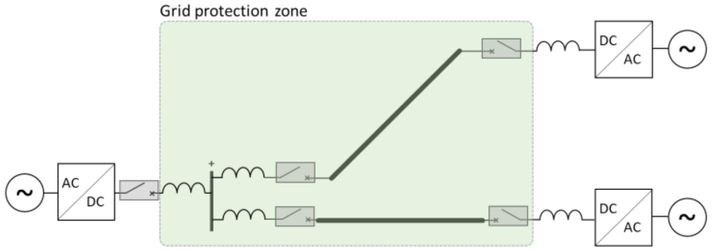
Protection strategy impact: fault clearing philosophy



- Fully selective fault clearing philosophy
  - Each line is a protection zone
  - Fault is suppressed by selective opening of the faulty line
  - Requires fast DC circuit breakers and high values of DC line limiting reactors



- Non-selective fault clearing philosophy
  - The entire grid is seen as a protection zone
  - Fault is suppressed by non-selective shutdown of the entire grid
  - Requires DC circuit breakers with relaxed requirement
  - MMC full bridge can be used to control the fault current to zero



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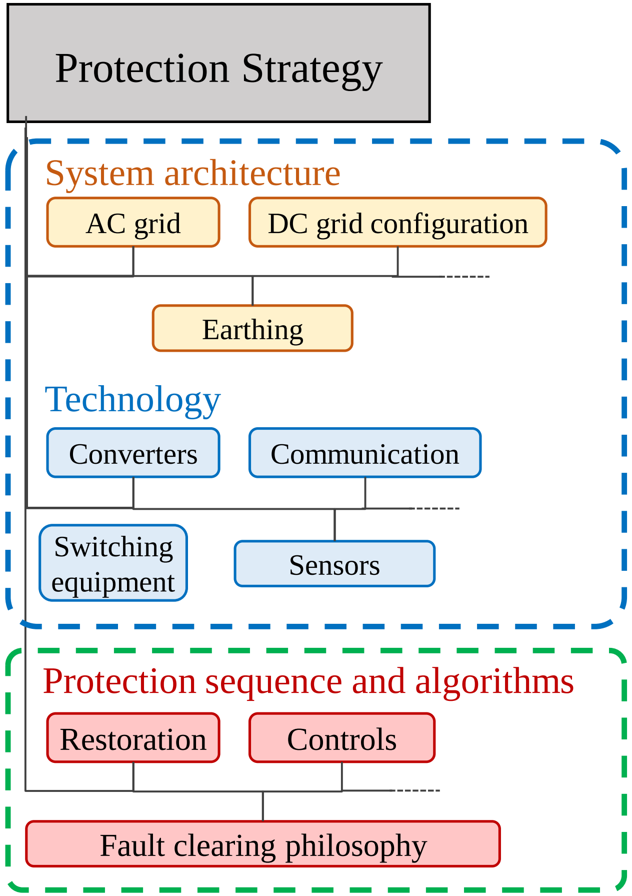
Protection strategy impact: need for coordination and common set of guidelines



- Development of protection strategy requires high level of coordination between system architecture and employed technologies
- System architecture and technology have great impact on the choice of fault clearing philosophy and design of control & protection schemes

- Interoperability at high level is needed in order to ensure coordination between protection switchgears, relays and MMC controls during the fault clearing and restoration processes.
- A common set of guidelines for protection sequence and algorithms would ease the future DC interconnections towards hybrid DC projects

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