Unlocking HVDC interoperability

Exploring the options for future MTDC projects

S. Silvant, C. Plet, C. Brantl, B. Luscan, M. Romero Rodriguez, L. Chédot

14/09/2020

SuperGrid Institute
Shaping power transmission

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

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Multi terminal DC grids

Future perspectives of development

- Public policies supporting the energy transition will trigger investment
- For TSOs, MTDC systems bring many benefits
- For OEMs, MTDC grids means new business opportunities
- MTDC technology is available

Technology, will and funds are there

Multi terminal DC grids

How to move forward?

- Large systems such as MTDC cannot rely on one single technology provider: MTDC grids need to involve multiple vendors

- How to ensure **interoperability** of converters provided by different vendors?

Appropriate technical framework should be defined ⟷ Appropriate contractual framework should be defined

- **New roles and new rules will have to emerge.**

Past and current initiatives

- Best Paths project
  - IOP issues, master control, integrator role
- CENELEC
  - HVDC Grid Systems and connected Converter Stations – Guideline and Parameter Lists for Functional Specifications
- PROMOTiON project
- ENTSO-E
- T&D Europe
- CIGRE WG-B4 85

Full consensus yet to be reached

Webinar objectives

- Share our technical analysis of interoperability
- Present possible directions we can take moving forward.
- We will consider the pros and cons of each option in order to provide a well-rounded view of the issues at hand.
- Representatives of the European PROMOTioN project will also present their vision on the subject in light of their recent studies.

Agenda

- Coordination & standardisation for Compatibility & interoperability in step-wise & organic development of multi-terminal, -national, -purpose, -owner and -vendor offshore HVDC transmission systems
  Cornelis Plet, 15’
- Towards DC side grid codes — Christina Brantl, 15’
- Organisational and Contractual framework — Bruno Luscan, 15’
- DC Grid control — Miguel Romero, 15’
- MMC control architecture options — Laurent Chédot, 15’
- Wrap-up — Sébastien Silvant, 5’
- Q&A — all, 15’

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Coordination & standardisation for Compatibility & interoperability in step-wise & organic developmentof multi-terminal, -national, -purpose, -owner and -vendor offshore HVDC transmission systems

Cornelis Plet

DNV·GL

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Coordination & standardisation
for
Compatibility & interoperability
in
step-wise & organic development
of
multi-terminal, -national, -purpose, -owner and -vendor offshore HVDC transmission systems

Cornelis Plet (DNV GL)

Webinar: Unlocking HVDC interoperability – 14th of September 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

What drives and shapes (offshore) grid development?

Drivers	Growth of renewables	Integration of the European energy market	
Objectives	Guarantee security of supply of energy	Minimise environmental impact	Minimise cost of energy
Principles	Competitive tendering	Non-discriminatory grid access	
Characteristics	(National) Technology neutral connection requirements	(National) Level regulatory playing field	

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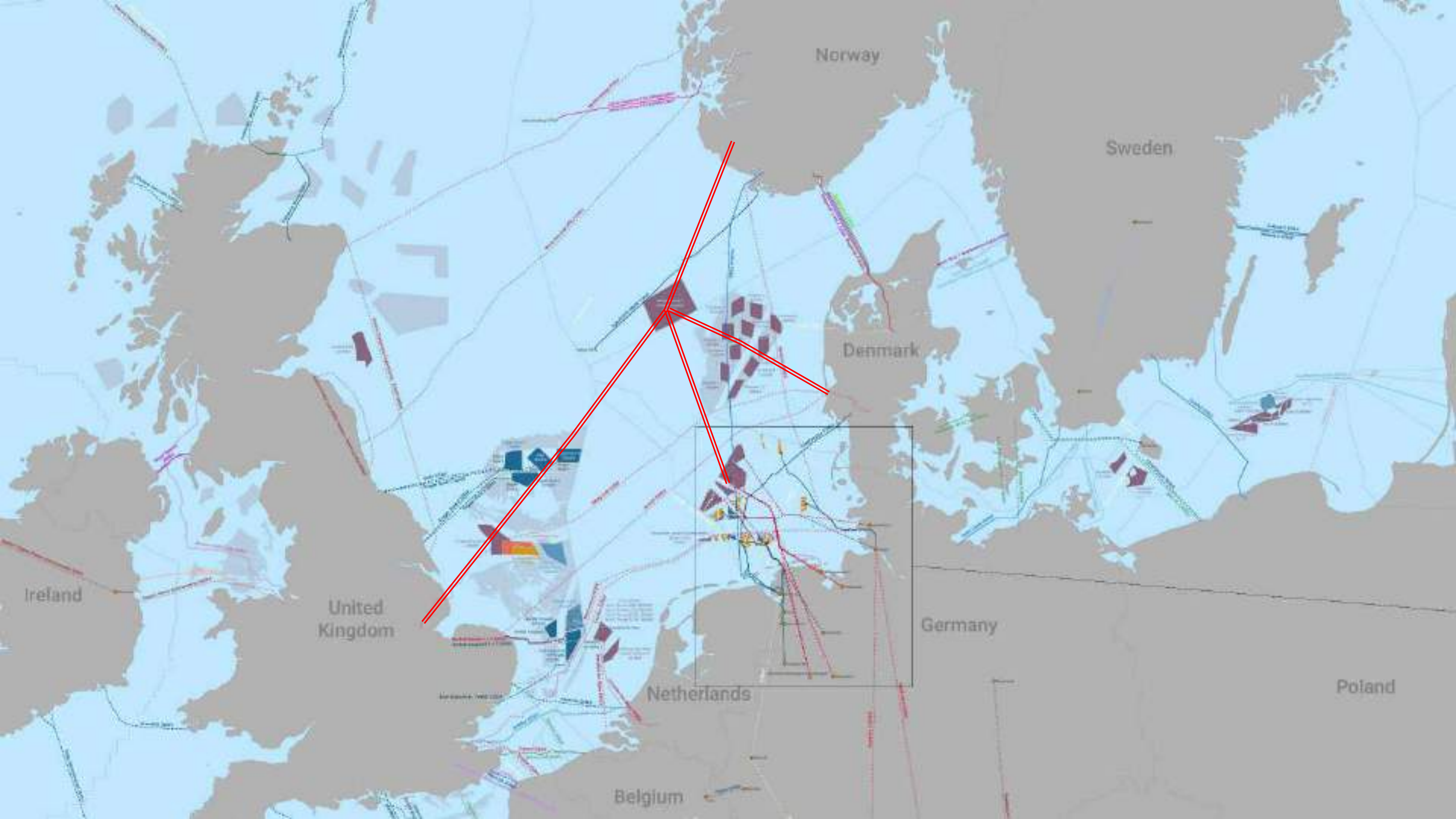

Norway
Sweden
Denmark
Ireland
United Kingdom
Germany
Netherlands
Poland
Belgium

Paradigm change needed

- Point-point
- Single-border
- Single-purpose
- Single-owner
- Single-vendor

→

- Multi-terminal
- Multi-national
- Multi-purpose
- Multi-actor
- Multi-vendor

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Objective

Determine the **minimum** set of regulatory agreements, functional requirements, technical parameters and project aspects…

…that need to be planned, agreed, coordinated, harmonized and/or standardized…

…to enable compatibility and interoperability of HVDC equipment & systems…

…to allow step-wise organic development…

…of multi-purpose, cross-border, multi-owner, multi-vendor, multi-terminal HVDC grids.

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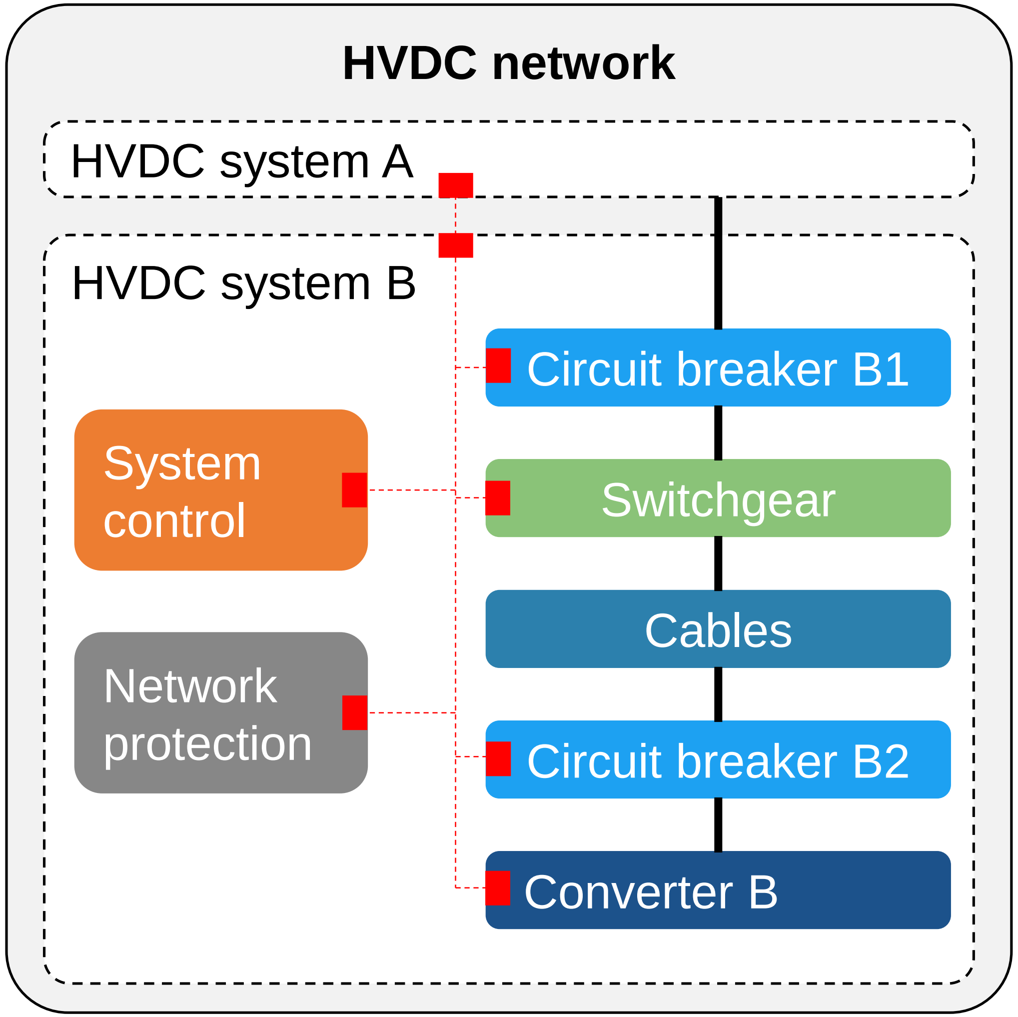
Compatibility vs interoperability



Compatible: capable of existing together in harmony → the ability of two or more HVDC systems or HVDC components to perform their required functions while sharing the same HVDC network

Interoperability*: the ability of two or more HVDC systems (or components) to exchange and subsequently use meaningful, actionable information across organizational boundaries:

- A common understanding "of the exchanged information,"
- An agreed upon "expectation for the response to the information exchange,"
- An obligatory "standard of service in information exchange: reliability, fidelity, security," availability

*based on IEEE 610 definition for software

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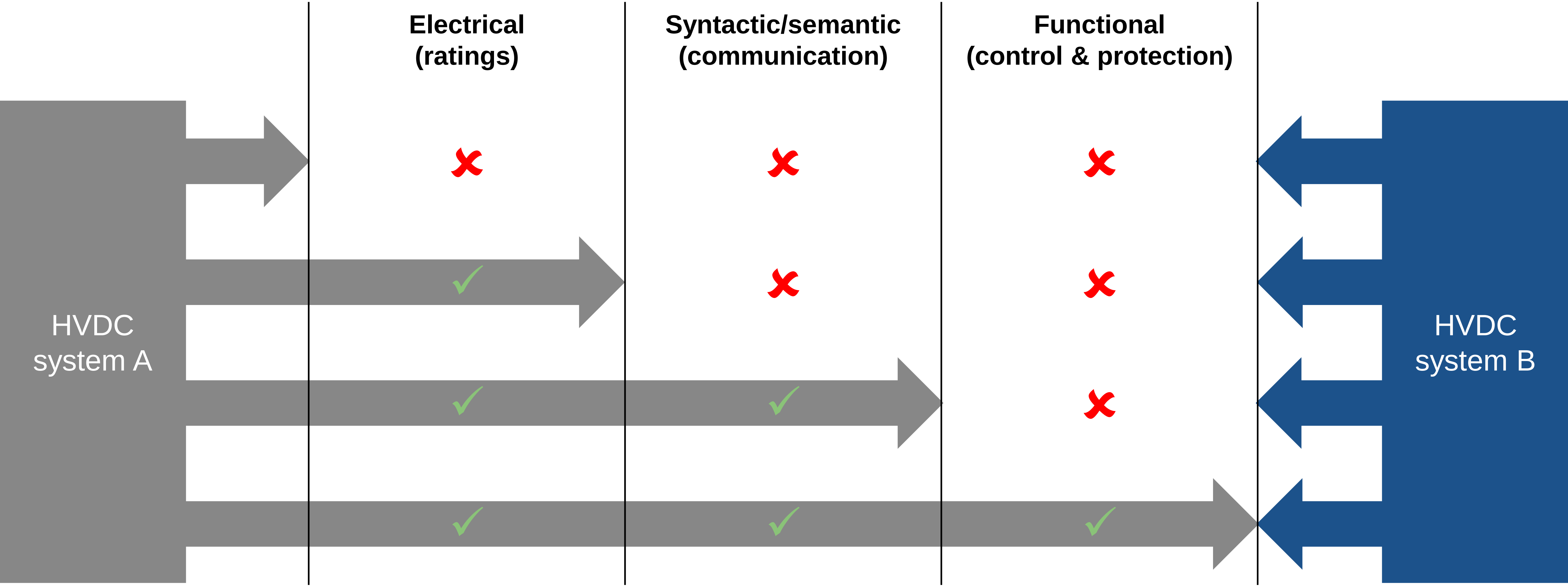
Aspects of technical compatibility



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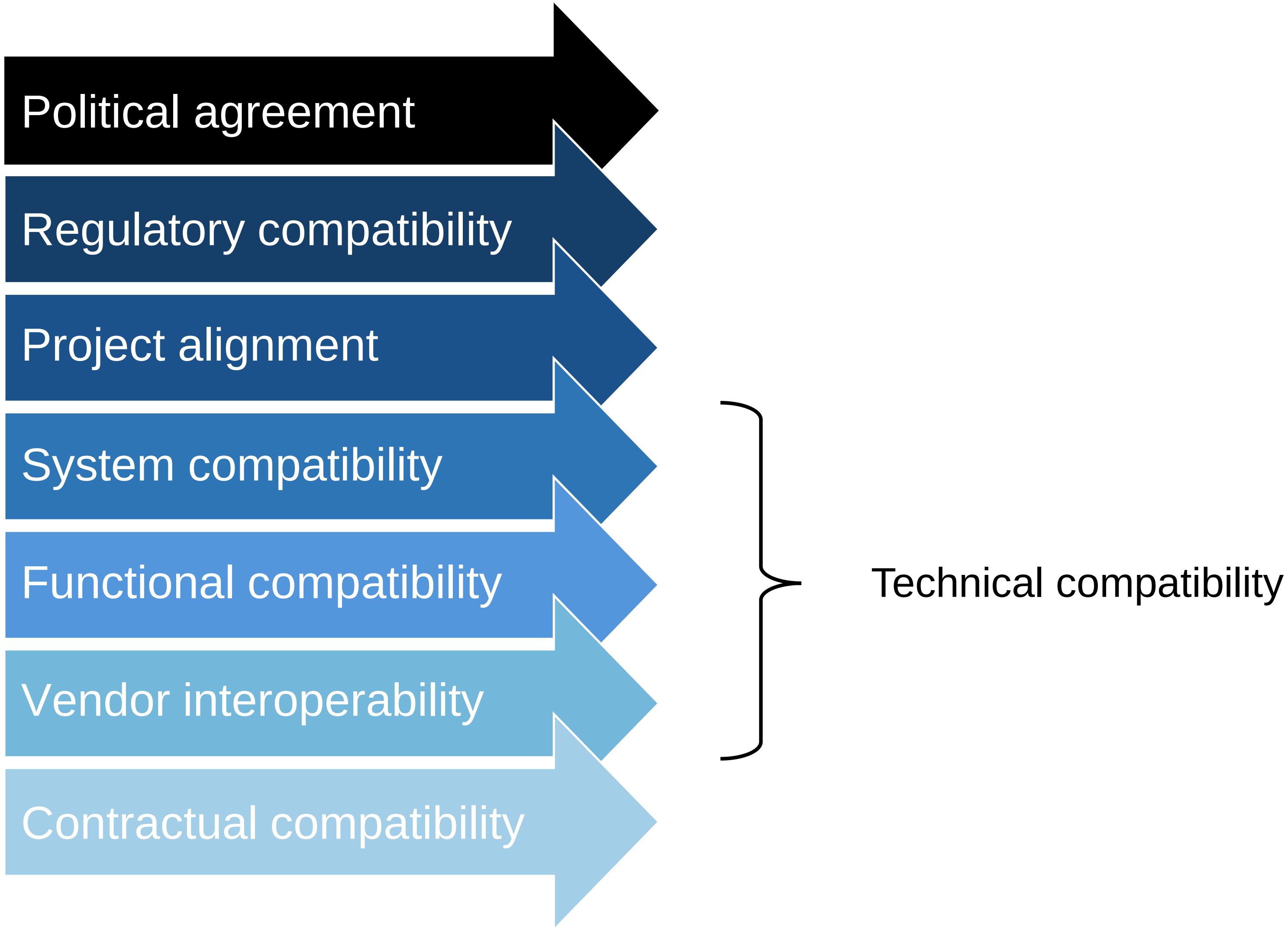
Seven levels of compatibility



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Adopt common vision of North Sea energy resources

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

Political agreement:

- International climate & energy targets
- National energy plans
- Quantification and split of costs and benefits
- Security of supply
- Cost of energy
- NIMBY / BANANA

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Align on multi-national power system rules of engagement

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

- (Maritime spatial) planning & permitting framework
- Market models
  - Hybrid assets
- Governance
- Support schemes
  - Anticipatory investments
- Decommissioning
- Conflict resolution
- System operation guidelines

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Coordinate power system planning regionally

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

- Master plannings
  - Power ratings
  - Terminal locations
  - Routes
  - Network options assessment
- Ancillary services
- Project timing & dependencies
- Project financing
- Expandability: Spare bay and space

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Agree on compatible electrical ratings for HVDC equipment

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

• Rated operating voltages
• Operational configurations
• Converter configuration
• Fault clearing strategies
• System earthing

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Agree on common functional requirements for HVDC equipment

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

- Control strategies
  - Modes (DC & AC) e.g. energy management, ancillary services and grid forming
  - Ramp rates
  - Limits
- Fault ride through
- Operational sequences
  - Energization
  - Reconfiguration
  - Restoration
  - De-energization

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Ensure compatible interfaces between different vendors' equipment

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

- Mechanical interface
  - Dimensions
  - Forces
  - Materials
  - Thermal aspects
- Communication interface
  - Signals
  - Syntax & semantics
  - Sampling rate
- Dynamic performance
  - Harmonic stability
  - Transient stability

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Align procurement best practise with new HVDC paradigm

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

- Procurement strategy
- Common terminology & definitions
- Completeness of requirements
- System integration responsibility
  - Interaction studies
- Warrantees, Liabilities & Conflict resolution
  - Operational performance e.g. Losses, Availability
  - Project delivery
- Exchange of information
  - Models
  - Interface definitions
- Technology qualification, testing & facilities

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Coordination & standardisation on all stakeholder levels is key

- Political agreement
- Regulatory compatibility
- Project alignment
- System compatibility
- Functional compatibility
- Vendor interoperability
- Contractual compatibility

Instruments

- Multi-lateral Treaty
- Regional (North Sea) Treaty
- North Sea Energy Cooperation
- TYNDP
- Memoranda of understanding
- System operational guidelines
- Grid codes
- Standards
- Recommended practises

Stakeholders

- National governments
- International bodies, EU, IMO
- National Regulatory Authorities, ACER
- ENTSO-E
- Transmission system operators
- Developers & Transmission owners
- Vendors
- Standardisation bodies

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Concluding remarks

- Incompatibility leads to suboptimal power system expansion
- Paradigm change needed in HVDC system development
- Coordination & standardization is necessary on political, regulatory, technical and business levels
- International harmonisation of project and system compatibility parameters is needed urgently
- Development of formal technical and operational rules of engagement should be initiated
  - Multi-vendor system integration best practise
  - HVDC system operational guidelines
  - HVDC system grid code

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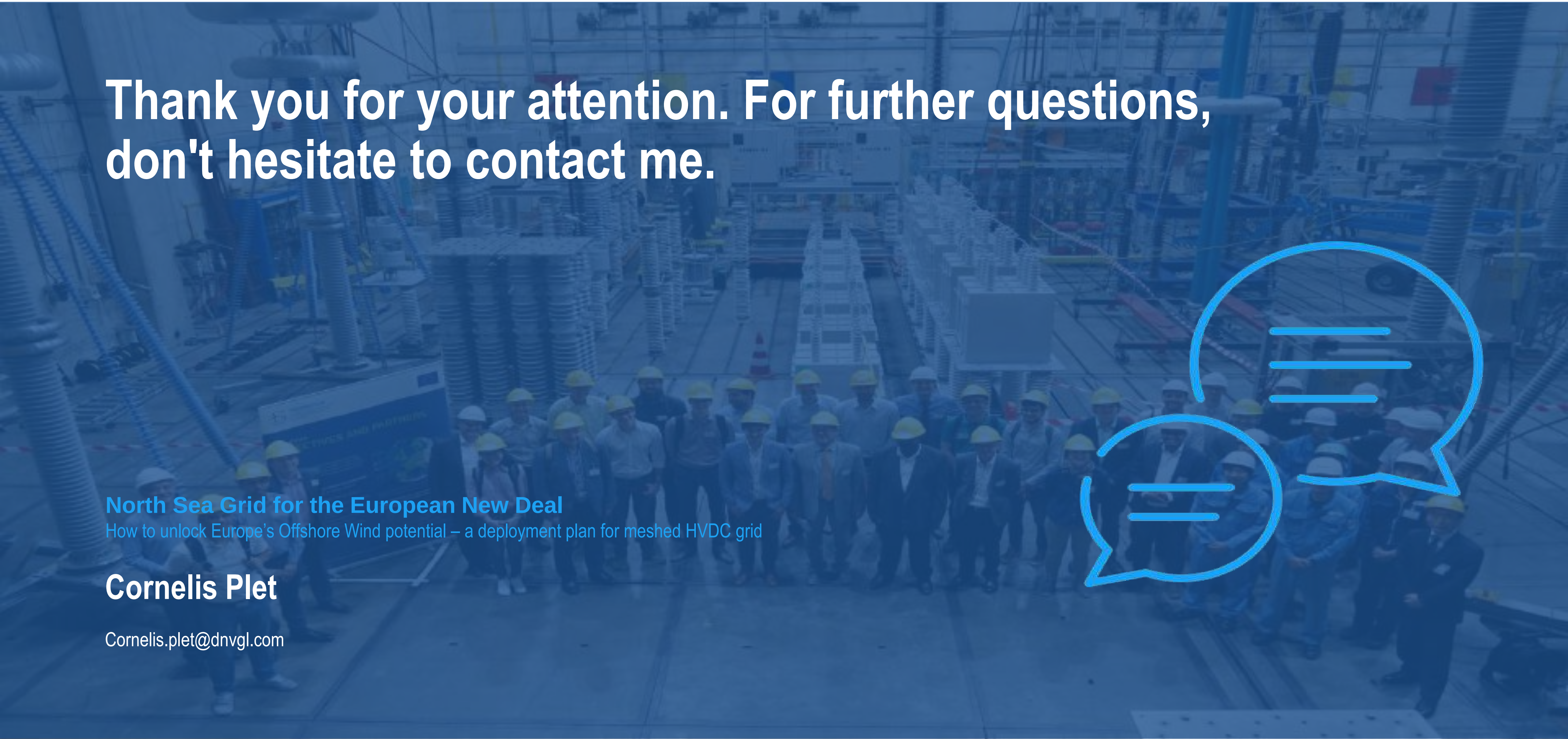

Thank you for your attention. For further questions, don't hesitate to contact me.

North Sea Grid for the European New Deal

How to unlock Europe's Offshore Wind potential – a deployment plan for meshed HVDC grid

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Towards DC Grid Codes

Christina Brantl

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Towards DC side grid codes

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Starting point in PROMOTioN: ENTSO-E network code

Published network codes

- Title: Network code on requirements for grid connection of HVDC systems and direct current-connected power park modules
- Specifies the converter behaviour at the AC point of connection
  - Frequency and active power related ranges and control modes
  - AC voltage ranges
  - Reactive power ranges and control modes
  - AC FRT and short circuit contribution
- No specific statements on the DC side
- The ENTSO-E grid code provides a broad range of possible specifications → further refinement in national implementations


I

REGULATIONS

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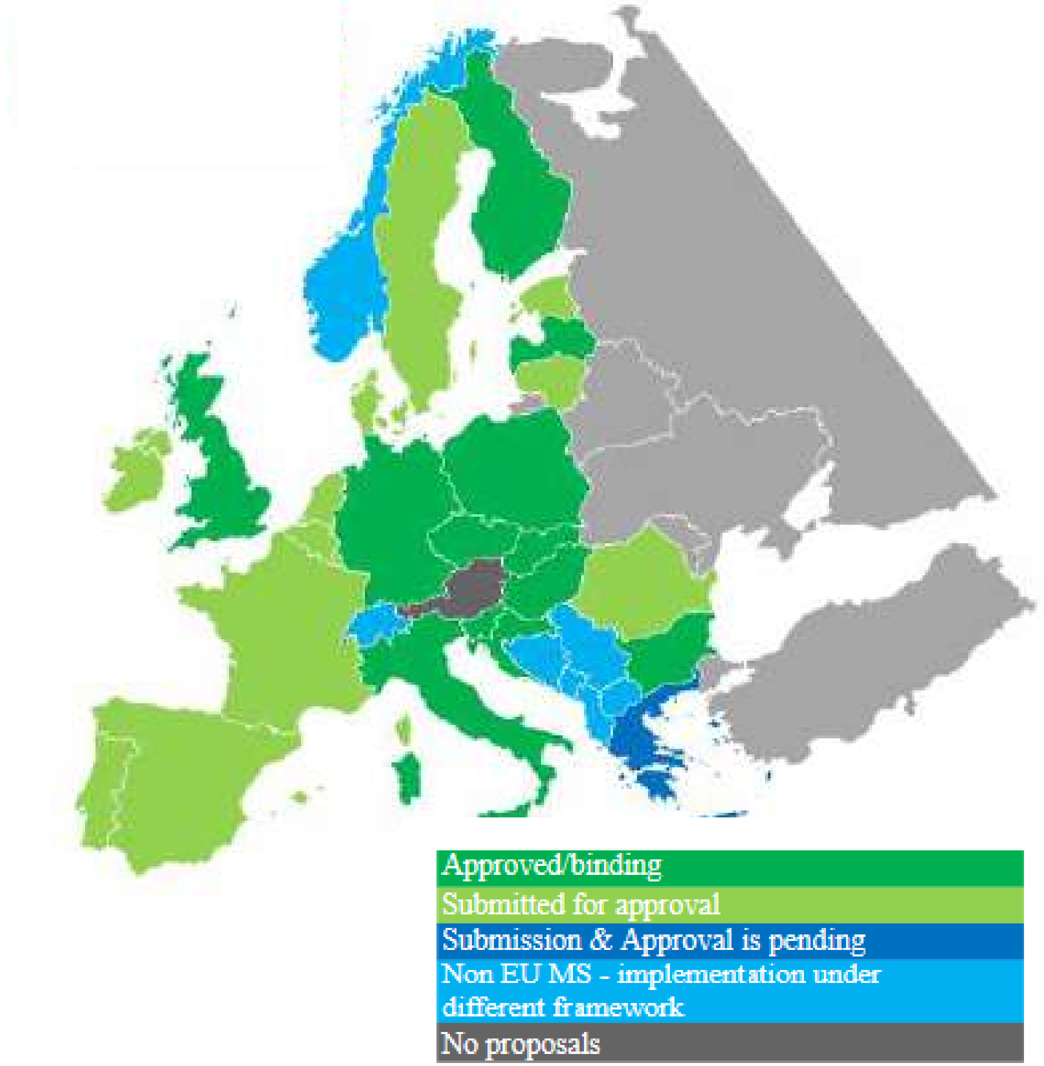
National Implementations

Observations

- Some aspects are specified in a similar fashion, e.g. AC FRT levels and the requirement of reactive power support
- Some national implementations exhibit more detailed requirements than others
- Some aspects are specified with different timings, e.g. fast fault current contribution
- Some requirements are imposed for some countries for others not (inertia provision)
- Some implementations specify requirements taking into account converter capabilities, some focus on requirements from the AC system perspective



(https://docs.entsoe.eu/cnc-al/#implementation-maps, accessed 18 June 2020)

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Design considerations for the development of multi-terminal HVDC grids

Normal Operation & System Design

- DC voltage level
- DC configuration
- Operational strategy
- Interoperability

Control of Offshore Wind Farms

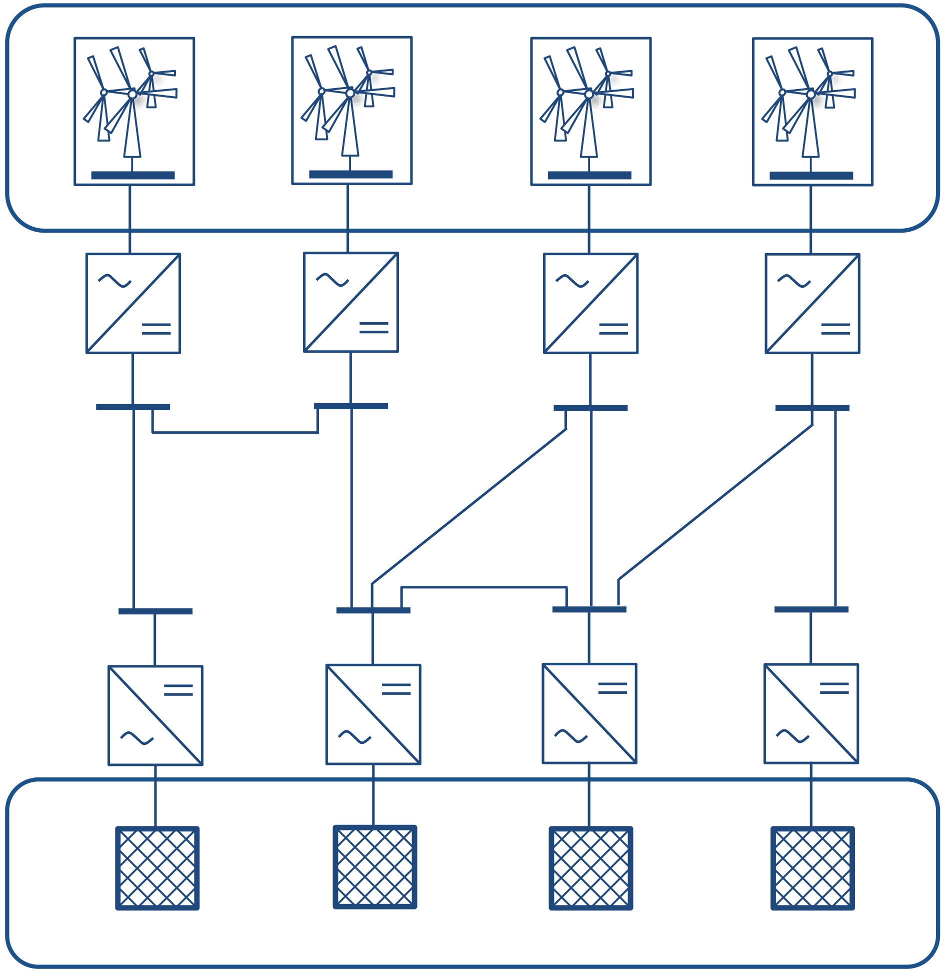
- Use of control capabilities for AC and DC FRT
- Grid-forming controls
- Black-start

DC side faults and contingencies

- Reliability and availability criteria
- Impact of faults and fault clearing strategies

AC system dynamics

- Provision of ancillary services
- AC FRT of the overall system
- Respect the different frequency reserves



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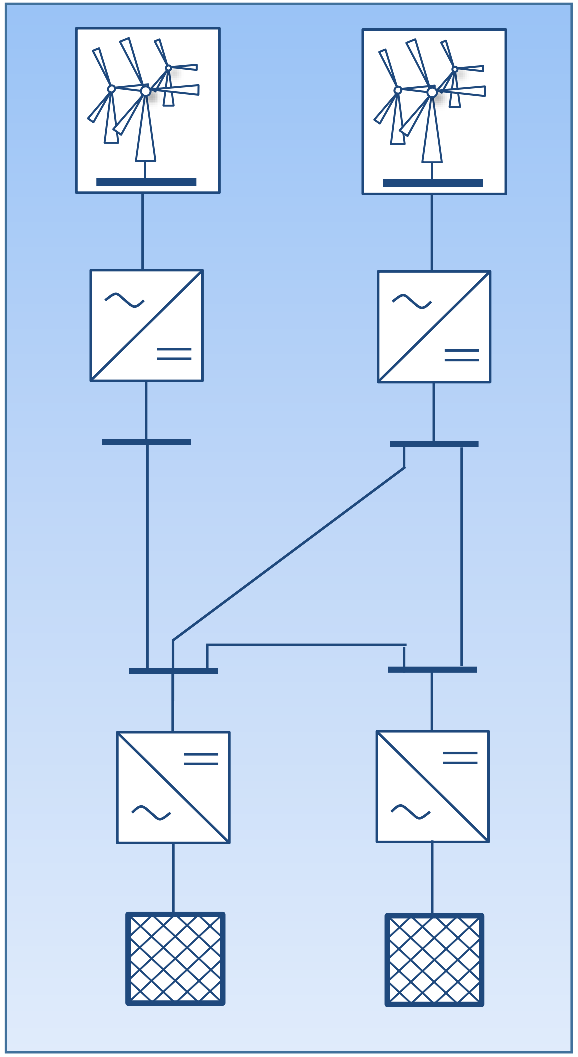
Requirements on HVDC Grid codes

Prerequisites

- Discrimination-free
- (Multi-vendor) interoperability
- Should be “plug-and-play”
- Should not inhibit technological development

Requirements on the Grid code

- Give functional requirements (at the point of connection for the converters)
- Should find a balance for different solutions and system requirements



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Challenges for specifying grid codes for HVDC systems

Basis for AC transmission system grid codes

- Given system voltages, given grounding strategy
- Known (passive) behaviour of generators under faults
- Standardised fault clearing sequences and components

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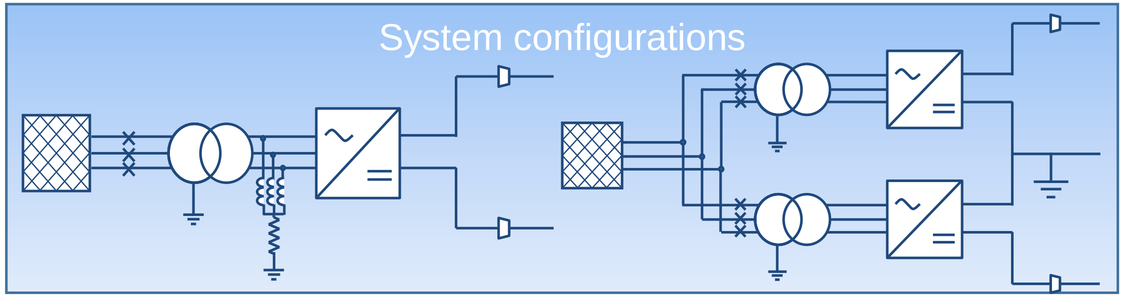
Challenges for specifying grid codes for HVDC systems

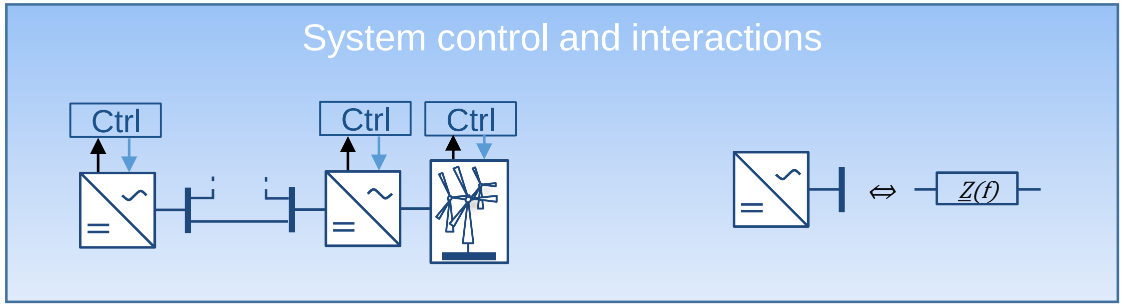
Basis for AC transmission system grid codes

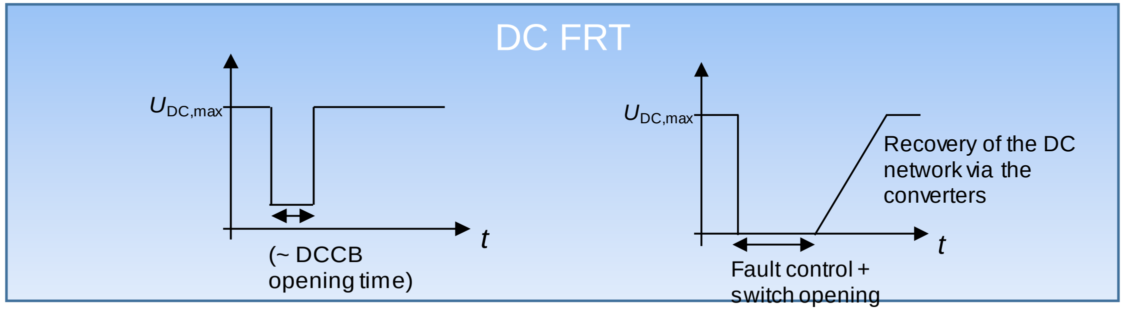
- Given system voltages, given grounding strategy
- Known (passive) behaviour of generators under faults
- Standardised fault clearing sequences and components

Planned and existing DC systems

- Range of DC system voltages
- Symmetric monopole configuration and bipole configuration with different grounding strategies
- Converter behaviour and capabilities depend on the converter type and the controls
- Different fault clearing strategies proposed







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DC Grid Codes: Building blocks and intermediate steps

Broad range of possible system designs and on-going technological development

Grid code that allows plug-and-play integration of new converters and other components

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DC Grid Codes: Building blocks and intermediate steps

Broad range of possible system designs and on-going technological development

Understanding of system behaviour and implications of design choices

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Understanding of system behaviour and implications of design choices

Decision for certain system designs

Specification of required system behaviour

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DC Grid Codes: Building blocks and intermediate steps

Broad range of possible system designs and on-going technological development

Understanding of system behaviour and implications of design choices

Decision for certain system designs

- Voltage levels and ranges
- System configuration and grounding
- Definition of protection zone boundaries

Specification of required system behaviour

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DC Grid Codes: Building blocks and intermediate steps

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Understanding of system behaviour and implications of design choices

Decision for certain system designs

- Voltage levels and ranges
- System configuration and grounding
- Definition of protection zone boundaries

Specification of required system behaviour

- Interaction between AC and DC system
- Power balancing mechanisms
- Robust control specification

Grid code that allows plug-and-play integration of new converters and other components

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GAP

GAP

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DC Grid Codes: Building blocks and intermediate steps

Broad range of possible system designs and on-going technological development

Understanding of system behaviour and implications of design choices

Decision for certain system designs

Specification of required system behaviour

GAP

Bridge: Interaction studies using impedance models, EMT models, replica systems, hardware-in-the loop analysis, …

GAP

Grid code that allows plug-and-play integration of new converters and other components

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Organizational and contractual framework

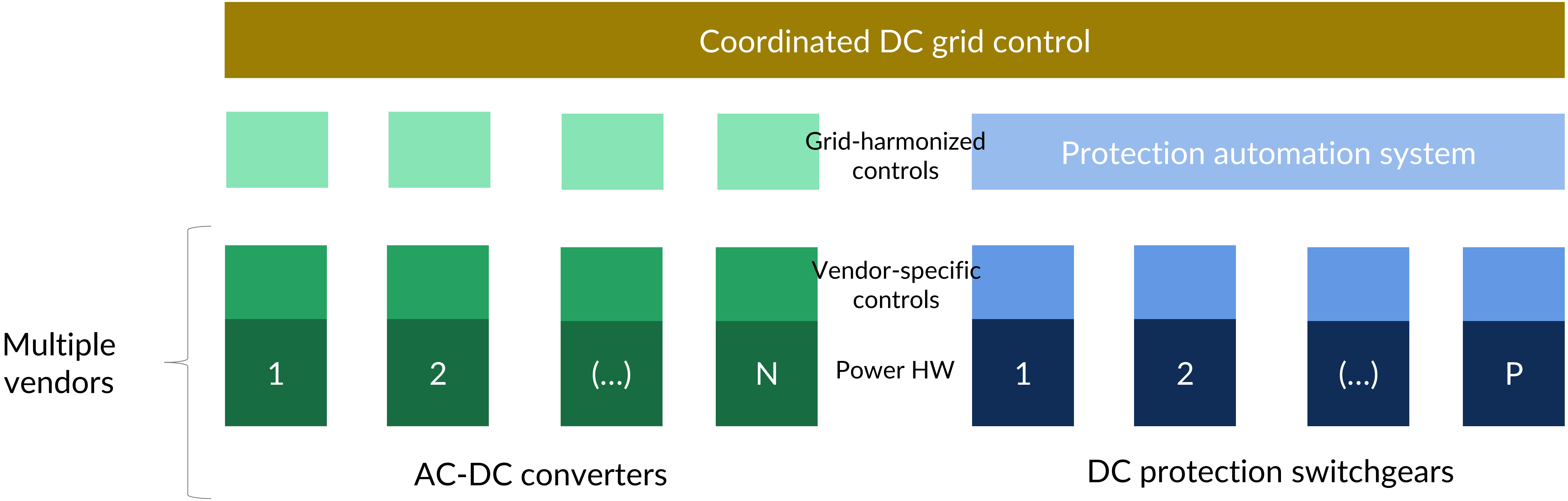
Bruno Luscan

Table of content

Preliminary remark:
This presentation does not propose one single organizational & contractual framework.
It rather explores different aspects and options, to highlight organizational framework importance for unlocking HVDC interoperability.

Organizational framework

Introduction: HVDC interoperability playground



It is about achieving C&P sub-systems integration and overall performance, in an efficient manner

DC grid asset ownership model

Single Owner

Initial development

JV between stakeholders ('Transmission company')

Responsible for asset development

Defines objectives for operational performance

Practical option for first MTDC development

Multiple Owners

System expansion

DC interconnection of two HVDC grids

Each DC grid keeps its own C&P system

Coordination functions

Logical evolution

"DC grid code model"

Converter stations may be owned by different entities

Technology, regulation and markets are not mature for this option to be operational for first MTDC grids

Single ownership will be assumed in following slides

Organizational framework

Who is involved?

Asset Owner / Developer

	Converter vendors	DC switchgear vendors	Protection automation vendors	Grid automation vendors
Technology providers	Converter vendors	DC switchgear vendors	Protection automation vendors	Grid automation vendors
C&P sub-systems	Internal converter controls DC node voltage control	Internal DCCB controls	Protection algorithms and sequences	Coordinated DC grid control

Who else, to achieve C&P interoperability by design and smooth integration ?...

C&P Integrator ?

What roles for an Integrator?

To <u>specify</u> C&P system

- Full functional specification
- Selected technical specification
- Requires to gather vast knowledge

"ESSENTIAL"

To <u>design</u> critical C&P sub-system

- Technical specifications of C&P sub-systems
- Development of selected C&P sub-system(s)

"OPTIONAL"

To <u>test</u> C&P sub-systems integration

- SIL
- HIL
- Also in case of future upgrades

"MANDATORY"

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Organizational framework

Integrator model options

Option A: Single Public Integrator for EU

- A public legal entity, financed by EC / regulators / TSOs
- Risks are mutualized
- Commercial liability can be taken by the integrator
- Significant investment in the beginning to develop relevant expertise, possibly gathering it from vendors and research institutes

Option B: Multiple Private Integrators

- Let the "market" operate and have private companies providing their expertise and services
- Assumption: full financial support and commercial liability won't be carried out by private integrators
- This set-up may favor Integrators able to take care of System-level control design, especially DC grid coordinated control

Option C: Asset-specific Lab-based Integrator

- Each DC grid asset owner establishes an Integrator
- This Integrator is not only responsible during project development phase, but also during the entire life of the asset, when modifications and maintenance are necessary
- If the Integrator has access to enough expertise (eg: a JV with a technology provider), then it could handle specification and part of controls design

Option D: Vendor-cooperation-based specification

(per T&D Europe proposal)

Specification development is carried out on the basis of a cooperation between converter vendors:

- The asset owner/developer only express high-level system functionality and performance requirements
- Precise specifications result from cooperation between vendors, and thus vendor "buy-in" is expected
- Integrator could maybe facilitate this cooperation phase
- Integrator in charge of integration test

Organizational framework

Integrator model options comparison

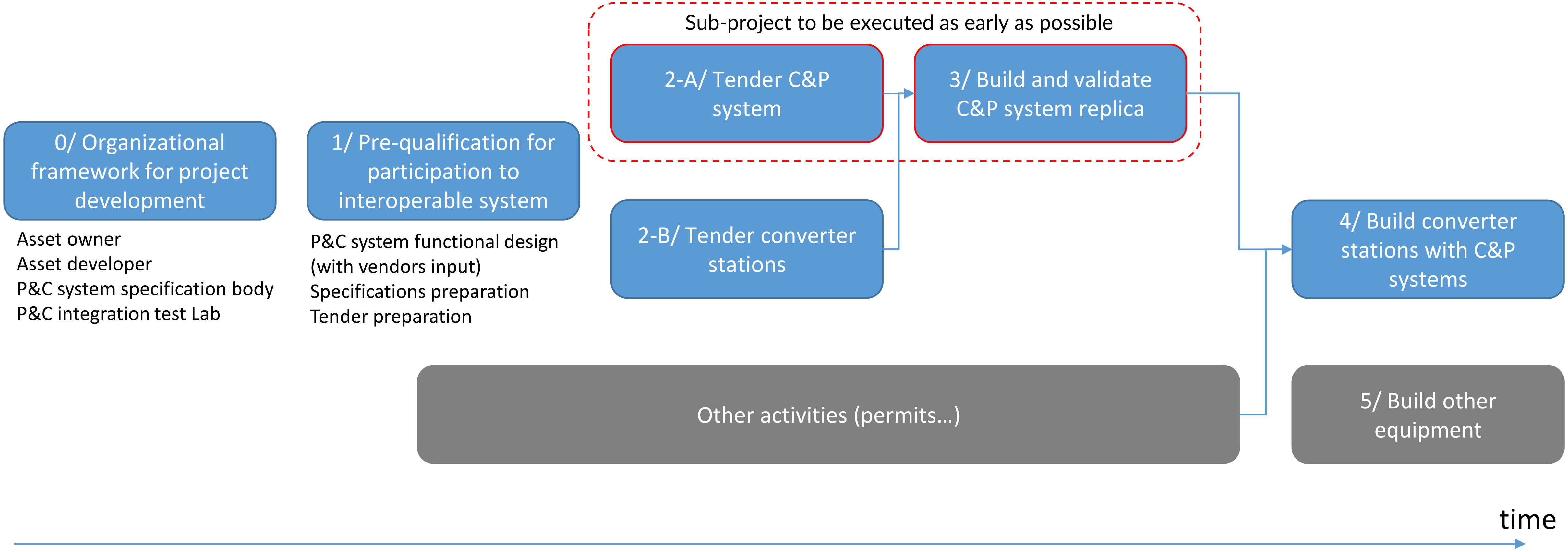
	Specification	Integration	Technical Responsibility	Commercial Liability (if specification has to be revised)
A – EU-level integrator	Integrated expertise	EU-level lab ??	Integrator	Integrator
B – Market-based	Consortium covering specification & integration			Asset developer
C – Lab-based	Lack of expertise	Regional lab close to asset owner	Integrator	Asset developer
D – Vendor-cooperation-based	HVDC vendors + facilitator	Regional lab close to asset owner	HVDC vendors	HVDC vendors

Requires effective governance and arbitrage

Organizational framework

Project tendering process

Aim: to anticipate and secure C&P sub-systems interoperability



IP-related aspects

Issue #1: to preserve vendors secret know-how

- HVDC control software embed a lot of know-how; only few technical features are patent-protected, a large part of the know-how is secret-protected.

Issue #2: to avoid harmful IP infringement investigation process

- Sharing vendor A converter control response with vendor B could trigger suspicion by vendor B that vendor A is infringing vendor B IP
- In such a situation, there should be a process to investigate if there is or not an IP infringement, which is acceptable for vendors (preservation of secret know-how; no lawyer nor cost for the investigation)

Issue #3: to organize fair licensing of necessary IP

- Achieving interoperability may require to use a patent, either owned by a converter vendor, or by another organization
- During pre-qualification stage, the integrator, together with participating vendors, has to identify such patents which may be necessary to use
- For a patented solution to be integrated in the specification, fair licensing conditions have to be defined and agreed during pre-qualification stage

↳ The Integrator role may also encompass IP-related aspects

Organizational framework

Synthesis

Asset ownership

First DC grid assets development calls for single ownership (possibly a JV between several stakeholders).

DC grid code will come at a later stage

Integrator model options

Having a single public integrator for EU could strongly facilitate HVDC interoperability

Market-based options do not suppress totally commercial risk for the asset owner

Integrator role

Key roles:

- Specification of C&P system
- C&P Integration tests

Technical expertise

(IP aspects)

Project tendering

Development and integration of C&P system should be handled as a sub-project, ahead of converter stations build

Thank you for your attention

DC Grid Control

From the CENELEC standard to a DC grid control of MTDC

Miguel Romero Rodriguez

Summary

- Role of the DC grid control
- MTDC network control system
- DC grid control architecture
- Further considerations

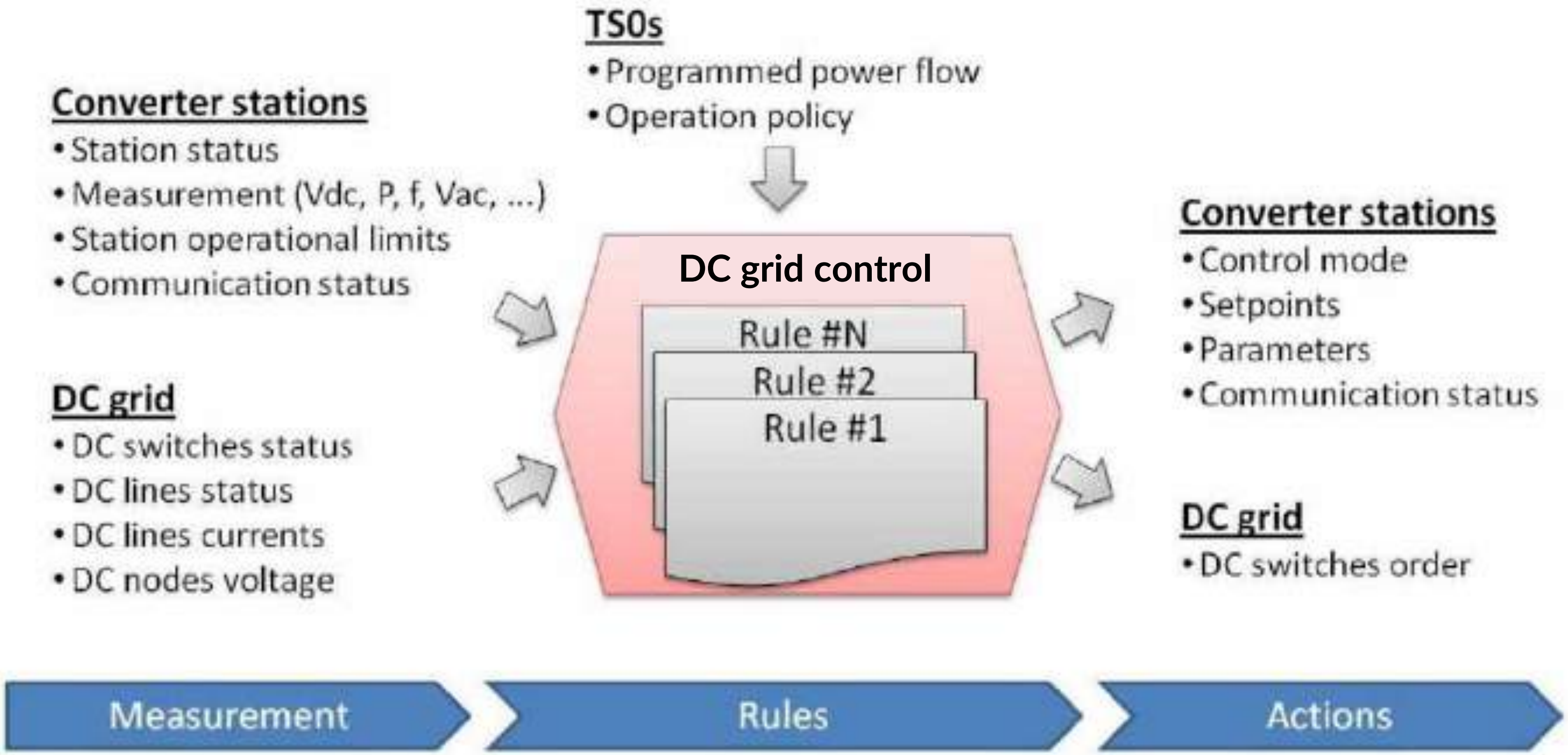
Role of the DC grid control

Interoperability enhancement

- **Coordination through an independent Master Control (or DC grid control) favored interoperability**
- **Need to clarify and agree on technical requirements and functions for successful control system development**
- **References:**
  - Best Paths D9.3, “Final recommendations for interoperability of multivendor HVDC systems”, 2018.
  - CENELEC standard. PD CLC/TS 50654-2:2018, “HVDC Grid Systems and connected Converter Stations – Guideline and Parameter Lists for Functional Specifications”, 2018.
  - ENTSO-E Standardized control interface for HVDC SIL/HIL conformity tests, 2020.

Role of the DC grid control

Functions



Deliverable 9.3, "Final recommendations for interoperability of multivendor HVDC systems", Best Paths, 2018.

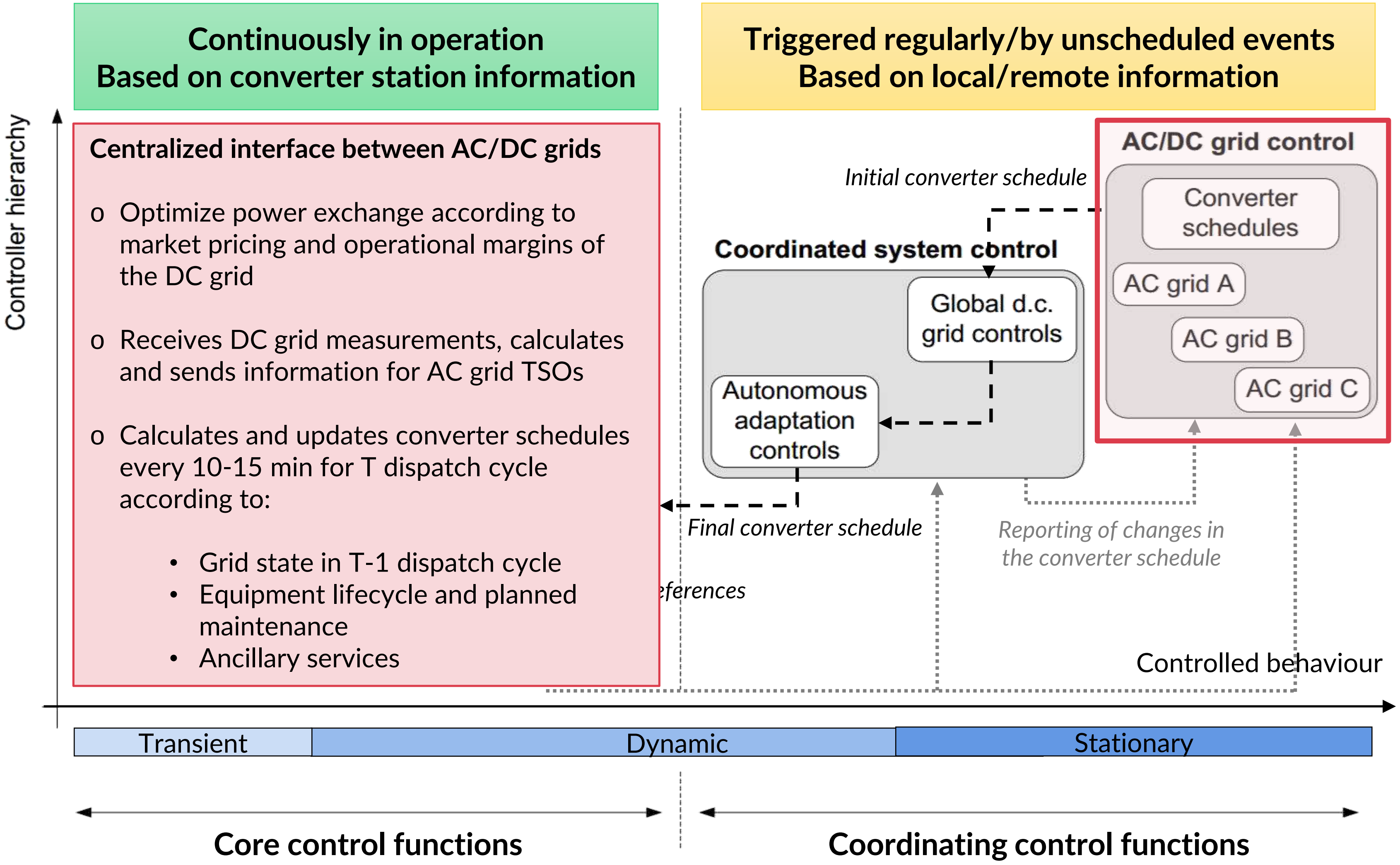
MTDC network control system

CENELEC standard

PD CLC/TS 50654-2:2018, “HVDC Grid Systems and connected Converter Stations – Guideline and Parameter Lists for Functional Specifications”, 2018.

Converter schedules for AC/DC or DC/DC converter stations:

- Control modes: specified by integer standardized for all vendors
- Control parameters (if any)
- Set points:
  - P_{dc}^*, V_{dc}^* [MW ; kV]
  - Q^*, V_{ac}^* [MVar ; kV]
  - ΔP_{ramp}, ΔQ_{ramp} [MW/s]



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MTDC network control system

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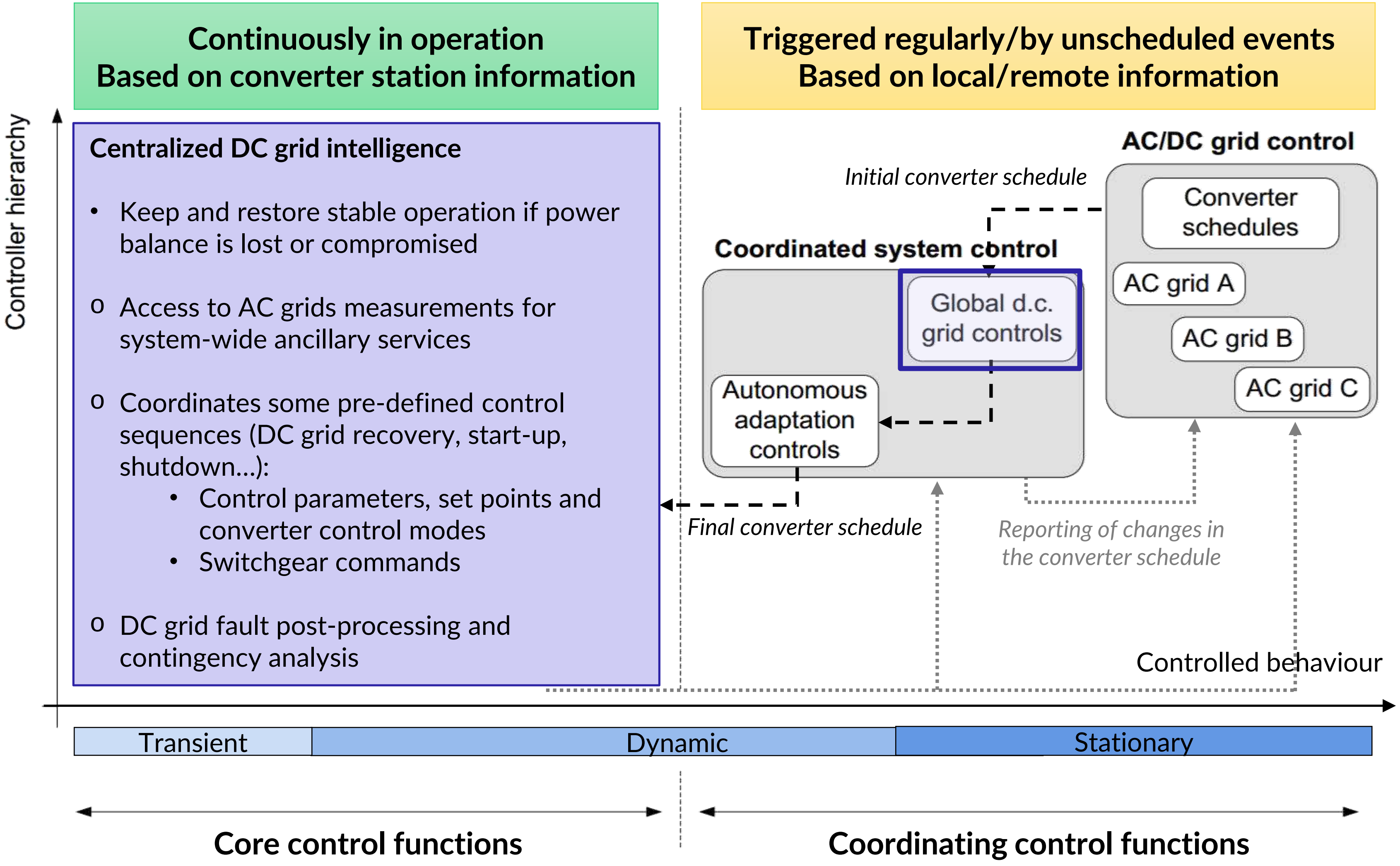

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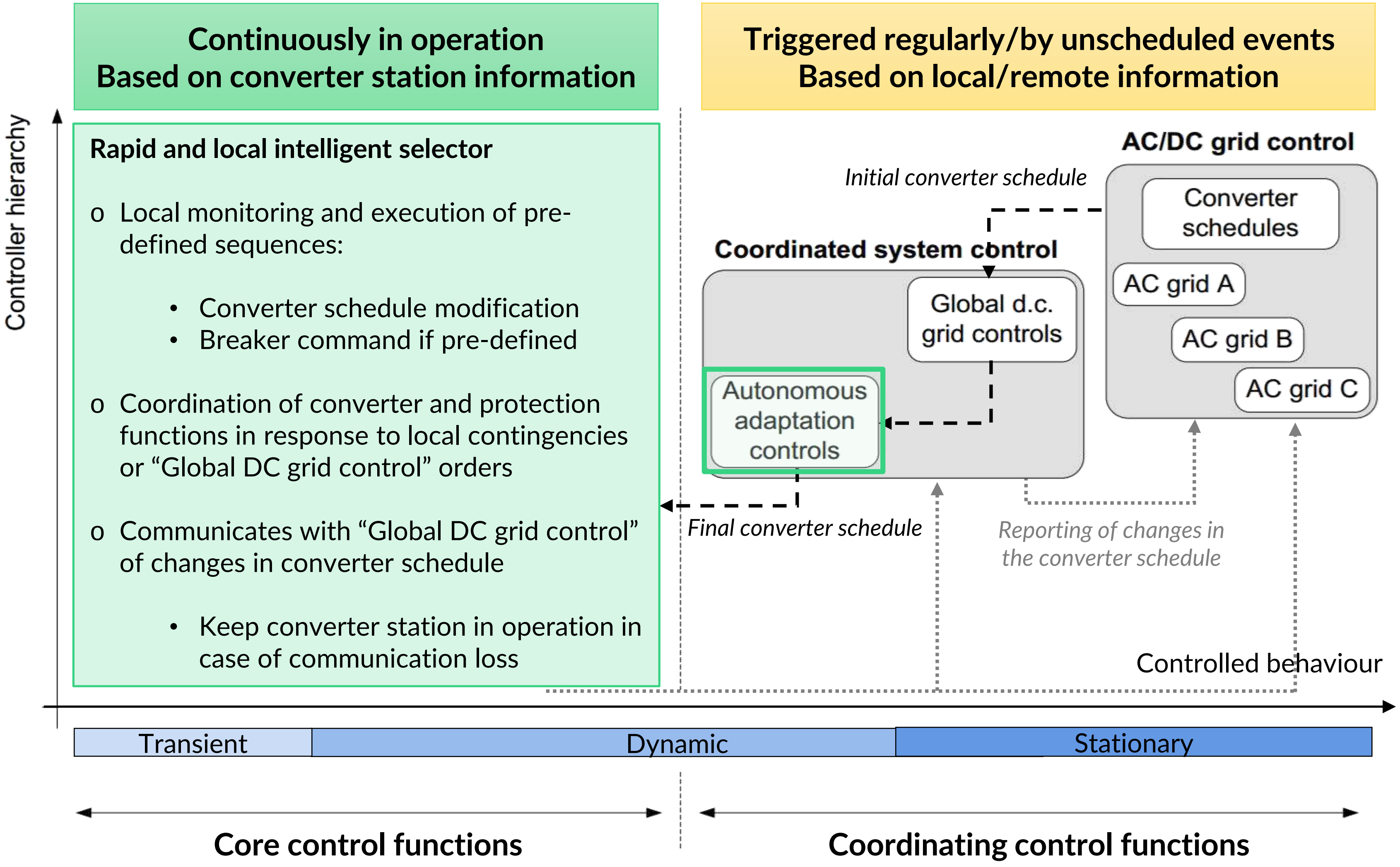
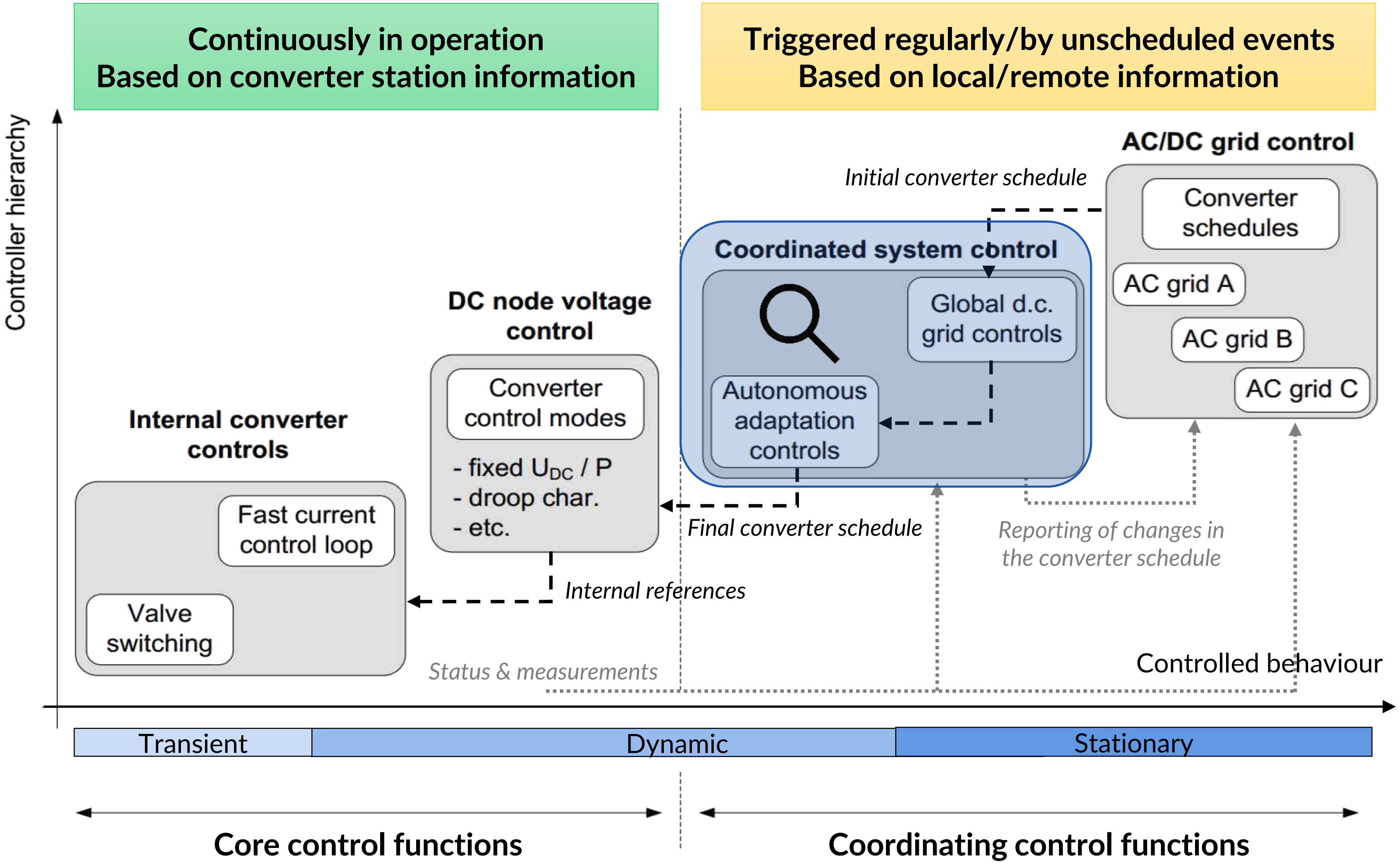


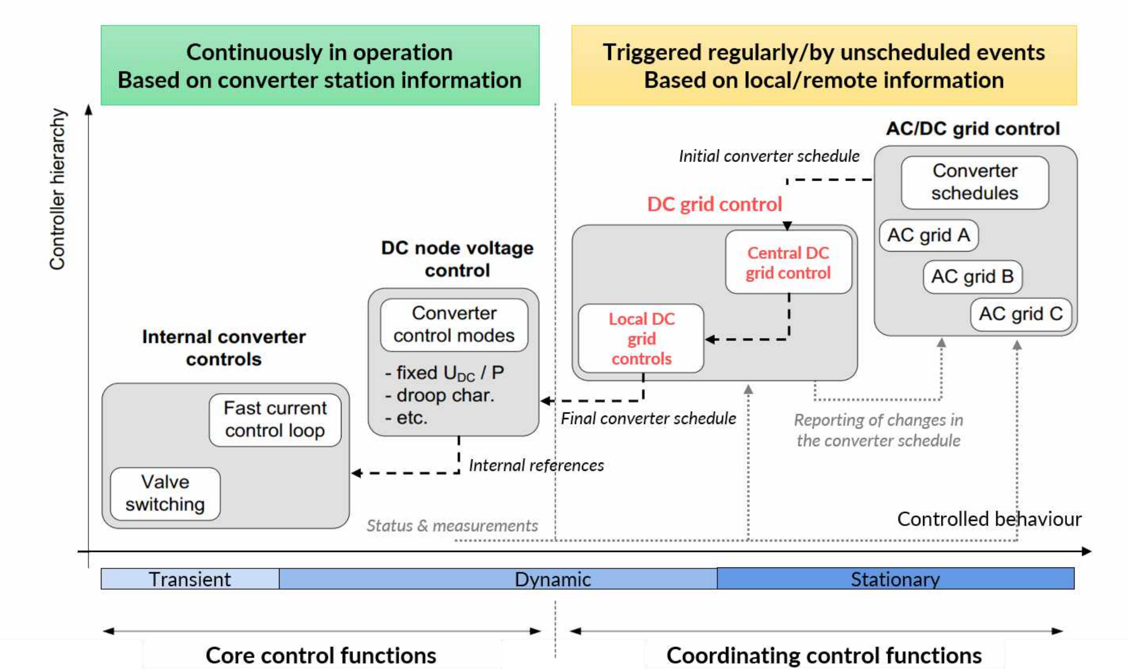
DC grid control architecture

SuperGrid Institute study

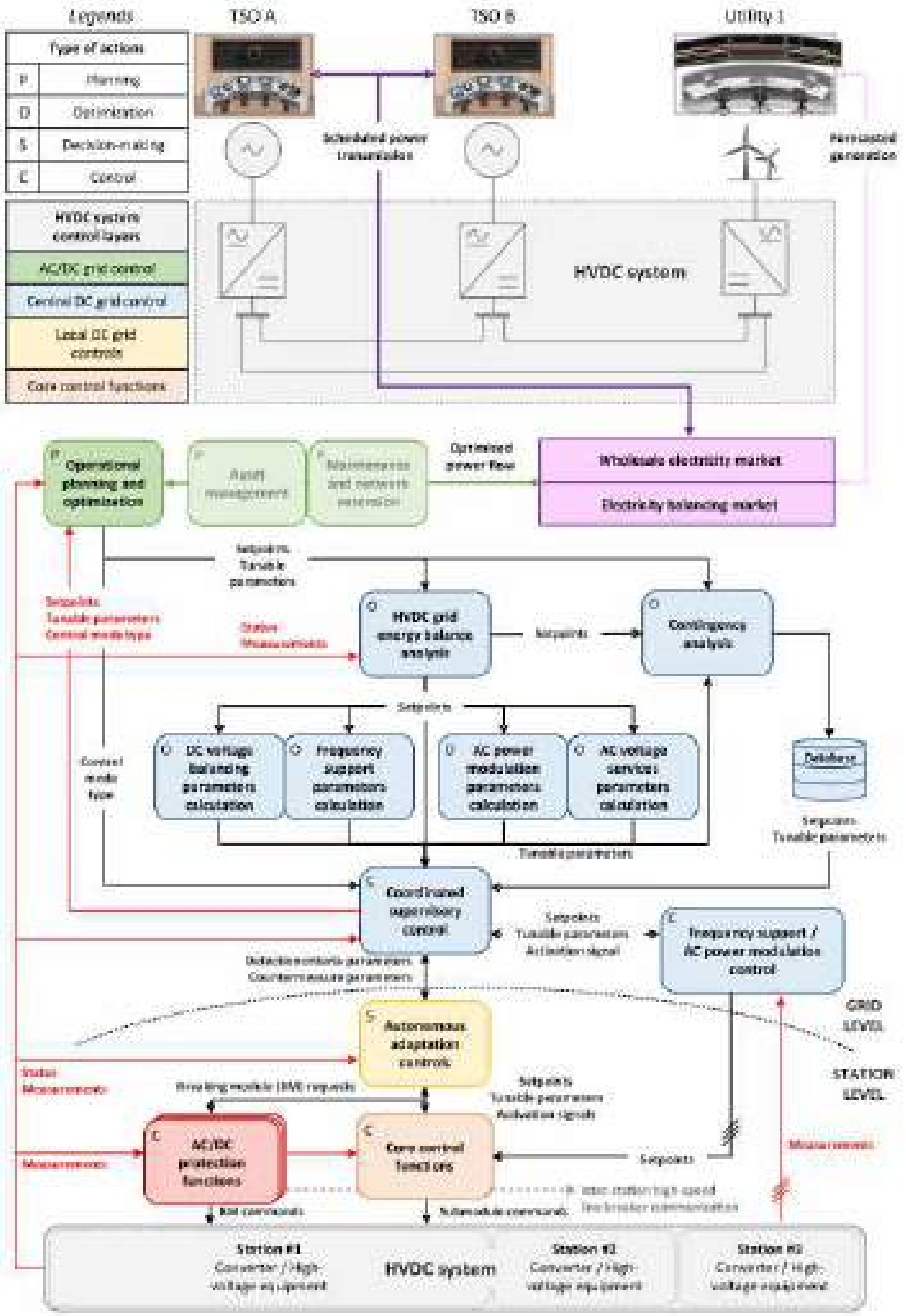


DC grid control architecture

SuperGrid Institute study



Detailed study of the control blocks inside each layer



First implementation in progress within PROMOTioN WP9

https://www.supergrid-institute.com/ | https://www.promotion-offshore.net/

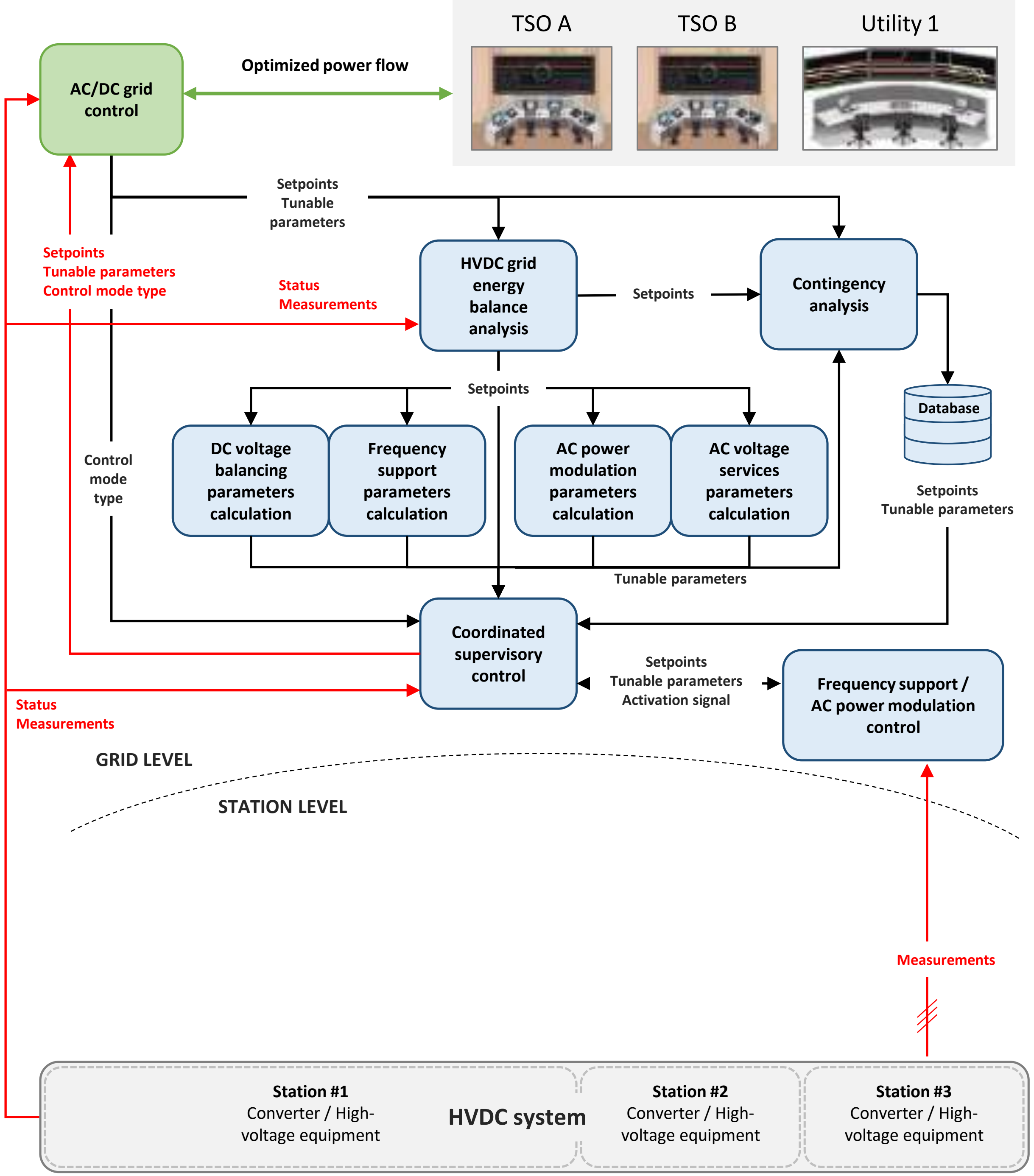
DC grid control architecture

Functional specification

MTDC network control layers
AC/DC grid control
Central DC grid control
Local DC grid controls
Core control functions
Protection functions

Central DC grid control objectives:

- Optimize to security margins the room for operating, remedial and ancillary functions
- Coordinate some pre-defined control sequences (DC grid recovery, start-up, shutdown…)
- Provision of system-wide ancillary services
- DC grid fault post-processing and contingency analysis



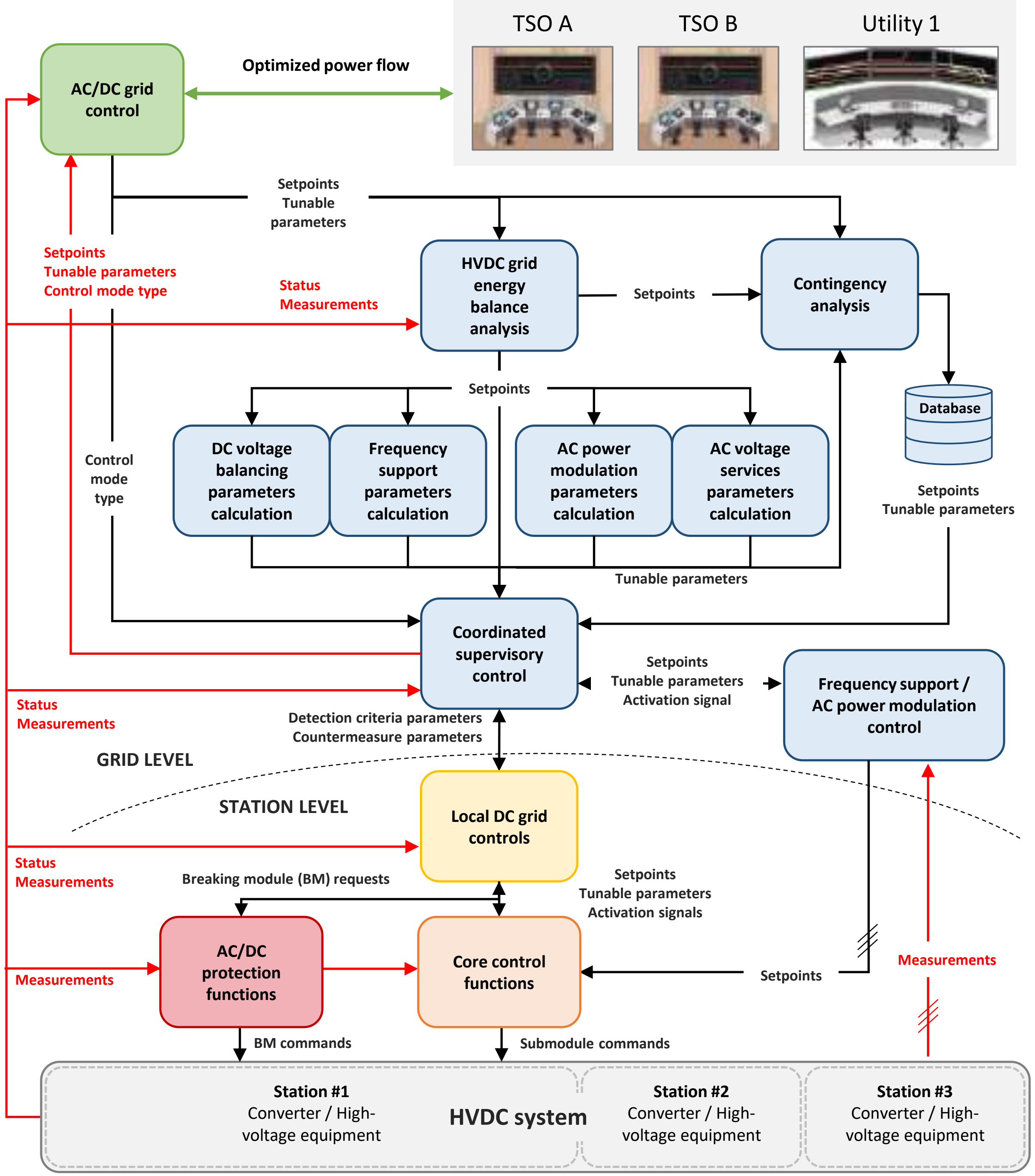
MTDC network control layers
AC/DC grid control
Central DC grid control
Local DC grid controls
Core control functions
Protection functions

DC grid control architecture

Functional specification

Local DC grid controls objectives:

- Local implementation of actions executed during sequences managed by Central DC grid control
- Continued converter station operation in case of loss of communication with Central DC grid control
- Interaction with core control functions and protection system for station-wide coordination



Further considerations

Control system implementation

Communication protocols:

- IEC 61850 for substation automation
- IEEE C37.118 for PMU measurements
- IEC 61970/61968 and CIM for EMS/SCADA APIs information exchanges
- IEC 62325 and CIM for energy market communications

Protocol harmonization is expected in the future

Implementation requirements:

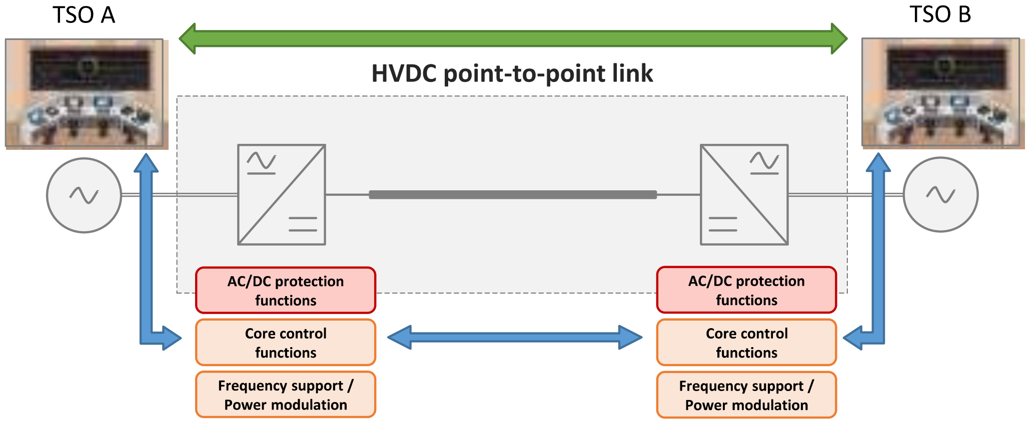
- The control hierarchy has consequences on:
  - **Time range in which control actions should be effectuated**
  - **Priority of operation during normal and abnormal operations**
  - **Available data (i.e. local or global measurements)**
  - **Actuator (i.e. local, distributed or centralized device)**

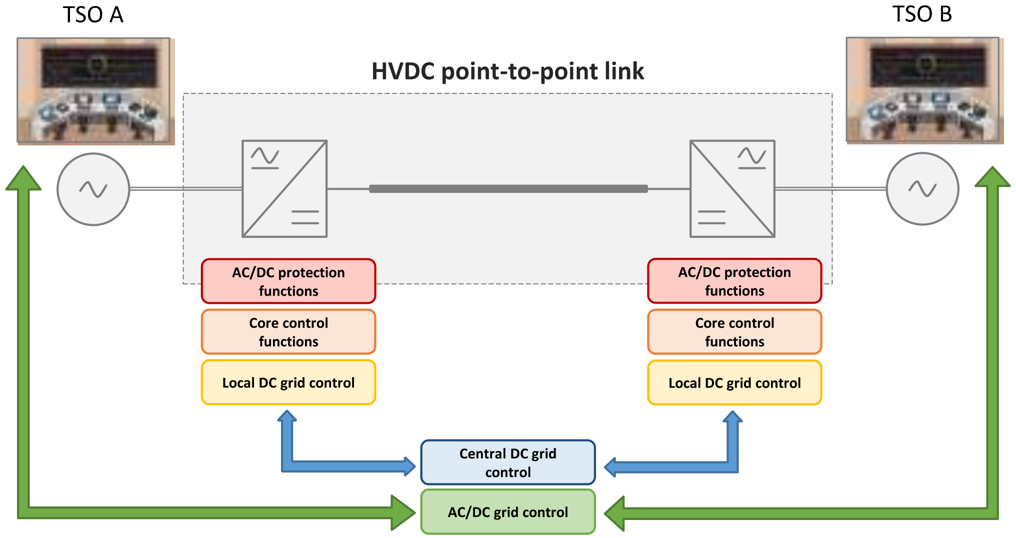
Further considerations

MTDC network development

- **Existing point-to-point links commissioned as part of isolated projects**

- **If newly built point-to-point links ready for multi-vendor interoperability:**
  - Seamless integration with compatible HVDC links
  - Most of the needed modifications realized in the centralized control layers





Thank you for your attention

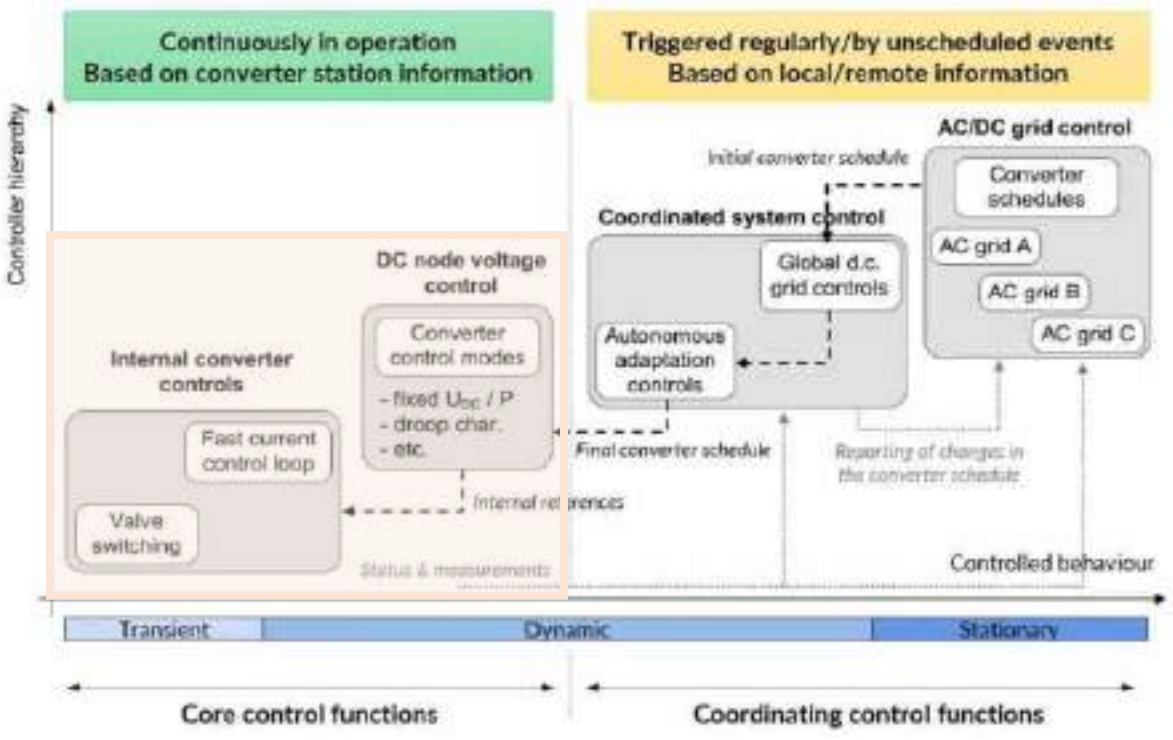
MMC control architecture options

Summary of the main options: extent to which control needs to be opened

Laurent Chédot

MMC control architecture options

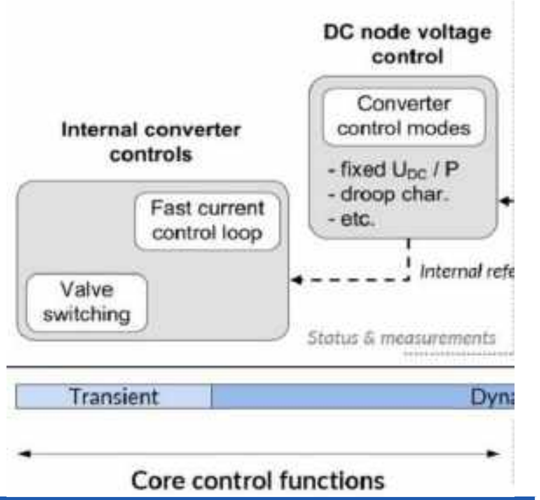
Reminder



Standard terms	Common terms	ENTSO-E standard interface control layer
Core control function	MMC control	
DC node voltage control	High level / Outer loops	
Internal converter controls	Low level / Inner loops	Converter-near control
- Fast current control loop	*- Inner high*	
- Valve switching	*- Inner low*	Module-near control and measurement-data acquisition

MMC control architecture options

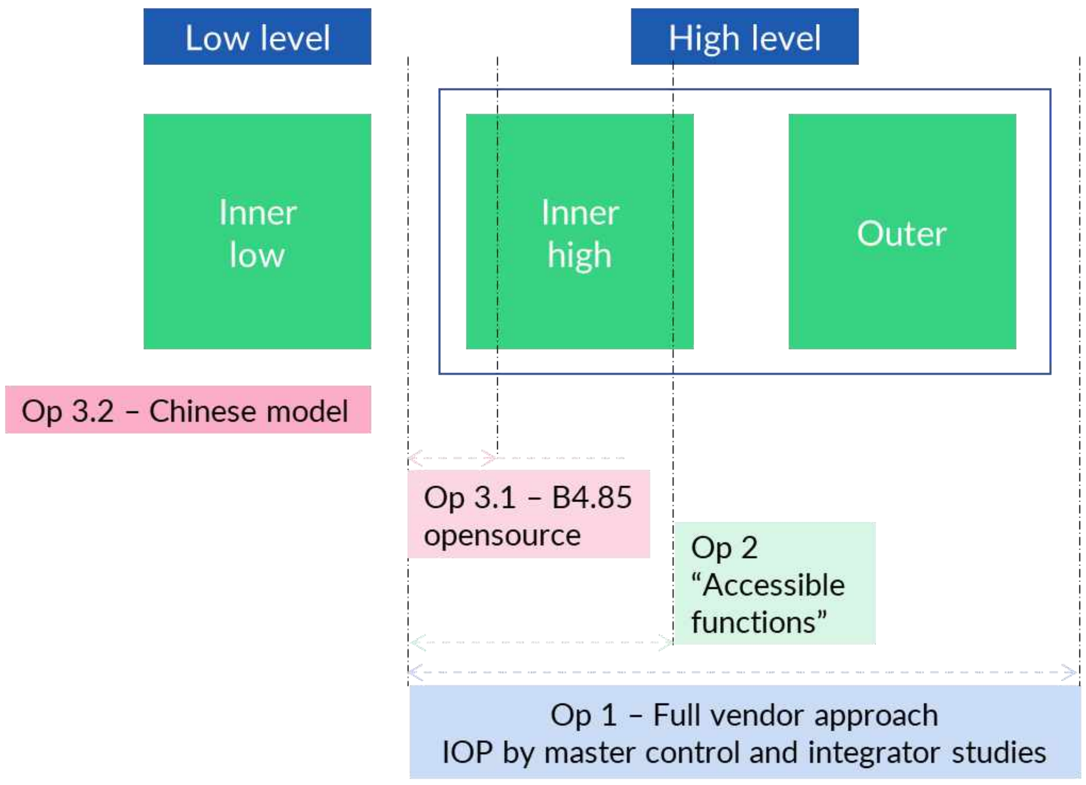
Reminder



MMC control	Main functions
High level / Outer loops *DC node voltage control*	Protection, supervision, converter management Active power control (P, Vdc) Reactive power control (Q, Vac) Global energy management
Low level / Inner loops *Internal converter controls*	
- *Inner high* *Fast current control loop*	*PLL* *Current regulation* *Phase/arm energy balancing*
- *Inner low* *Valve switching*	*Submodule balancing, modulation* *Hardware protection*

MMC control architecture options

Main options



Option 1: Vendor in charge of all control. The integrator manages interoperability issues thanks to DC grid control, system studies and HIL tests

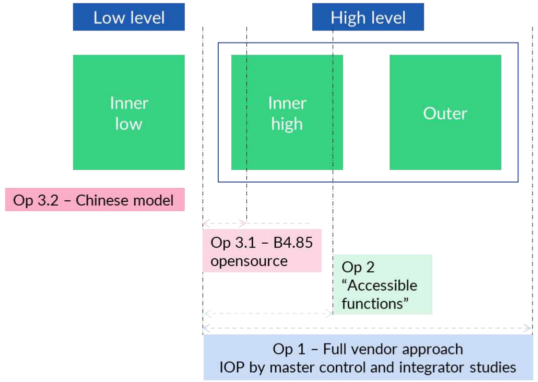
Option 2: Vendor in charge of all control, some functions accessible to the integrator

Option 3: Vendor in charge of low level (inner low control), integrator in charge of high level (inner high and outer control)

- Option 3.1: Cigré B4.85 approach: Vendor in charge of low level, integrator in charge of open-source high level
- Option 3.2: “Chinese model”

MMC control architecture options

Option 1: Vendor in charge of all control



- **1 vendor by station**
- **Integrator**
  - Coordinator to avoid IOP issues, steady state and dynamic
  - Specification and test facilities
  - IOP issues solving through DC grid controller and by asking control modification
- **Activities shared between vendors and integrators**
  - Control and protection architecture and strategy, dynamics performance tests, combined performance tests
  - Station level = vendor
  - Grid level = vendors + integrator
  - Key challenge: share data to solve potential IOP issues without IP infringement
    - ➔test facilities by 3rd party integrator

MMC control architecture options

Option 1: Vendor in charge of all control

Pros

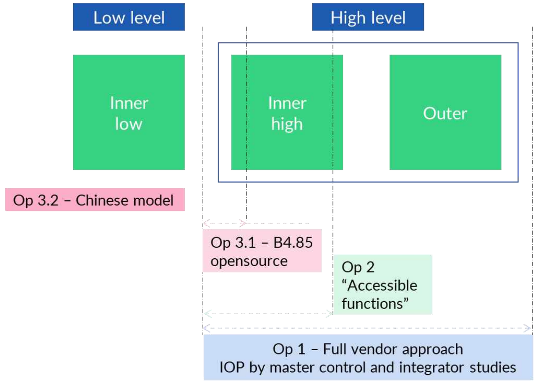
- Current model for MMC control architecture
- Optimized implementation
- Optimized software/hardware interface
- Vendor expertise
- Vendor Intellectual Property (IP) is protected (vendor control)
- Optimization of power electronics design and converter efficiency (optimized control delays)

Cons

- Integrators have very limited ways to solve interoperability issues
- If IOP issues persist, all vendors are sollicitated to update their control
  - may spent a lot of time
  - may leads to penalities
  - Integrator arbitrates ➔ responsabilities
  - Who pays ?
- Difficulties to manage IP of each vendors (tests results, ...): how to share data between vendor to understand IOP issues

MMC control architecture options

Option 2: Vendor in charge of all control, some functions accessible to the integrator



- **Option 1 with accessible functions**
- **A function "accessible to the integrator" should respect some criteria:**
  - The function is documented, specified or at least with a user manual
  - Inputs and outputs are defined and documented. Standardized if possible.
  - Some parameters should be editable with explanations, range, limitation and impact
- **Main accessible functions to solve IOP issues**

MMC control	Main functions
High level / Outer loops	Protection, supervision, converter management Active power control (P, Vdc) Reactive power control (Q, Vac) Global energy management
Low level / Inner loops	
- Inner high	*PLL* *Current regulation* *Phase/arm energy balancing*
- Inner low	*Submodule balancing, modulation* *Hardware protection*

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MMC control architecture options

Option 2: Vendor in charge of all control, some functions accessible to the integrator

Integrator expertise

- **In addition to MTDC management, complete mastery of the control: automatic, industrial computing and converter control**
- **Who ?**
  - TSO with expertise in control
  - TSO/Vendor association, dedicated to this kind of integration
  - third party: vendor, laboratory, technical studies office, …

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MMC control architecture options

Option 2: Vendor in charge of all control, some functions accessible to the integrator

Technical risks

- **solve IOP issues ➔ sensitive functions parameters tuning ➔ possible initial system behavior degradation**
  - Oscillations
  - Instabilities between converters
  - Instabilities inside converter control
  - Faults (overvoltage, overcurrent) producing breaking and tripping events
- **In case of fault or instability**
  - IOP issues or traditional control tuning issues?
  - Due to initial control tuning or accessible function tuning modification?
- **Workaround**
  - Limit and manage accessible function tuning ➔ configuration tools
  - Test facilities for IOP issues investigation

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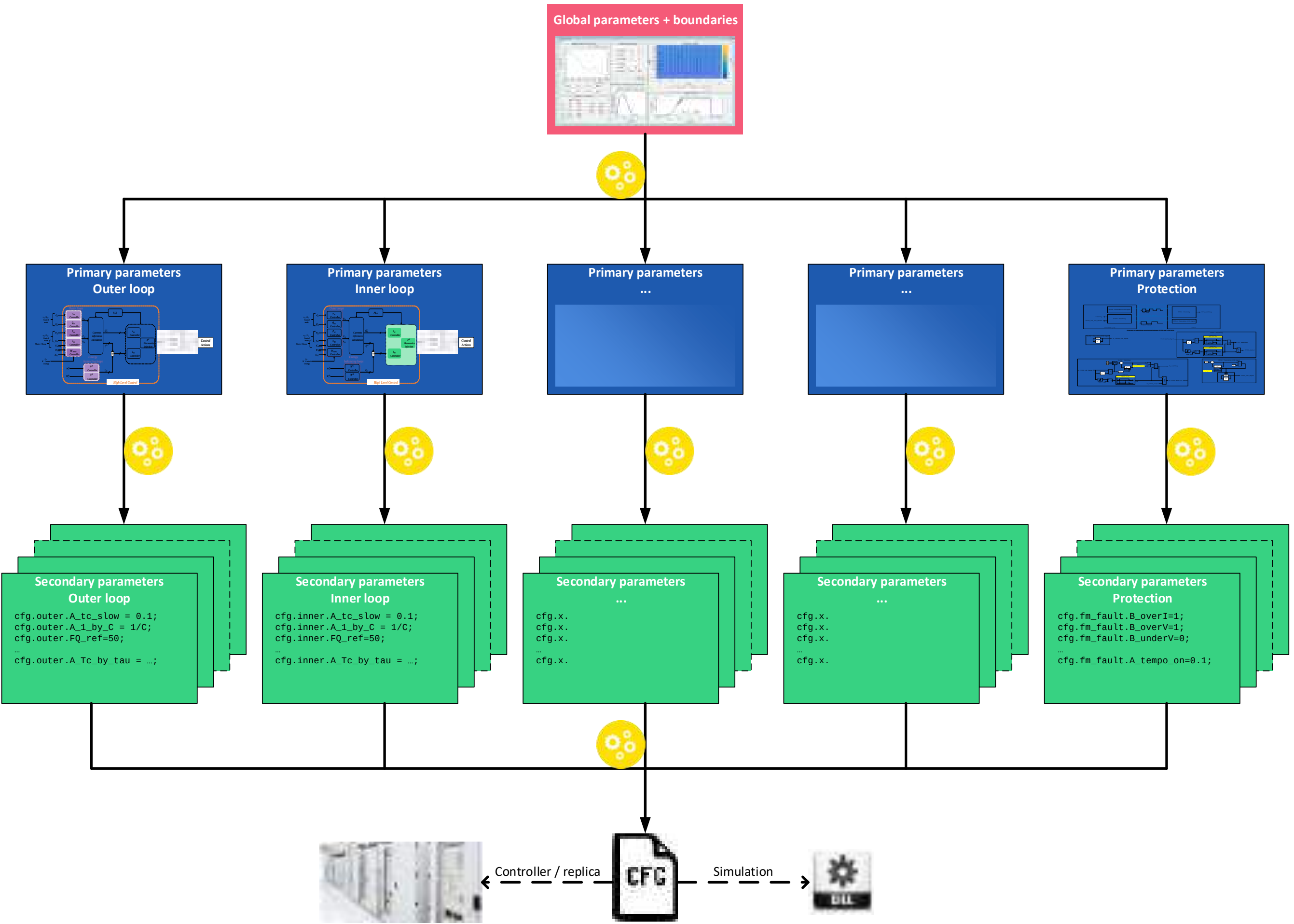
MMC control architecture options

Option 2: Vendor in charge of all control, some functions accessible to the integrator

Configuration tools



Characteristics

- Made and thought for integrators
- User-friendly interface
- Accessible functions tuning guide
  - **Explanations/behavior**
  - **Global parameters: global response time, filtering,…**
- Others *secondary* parameters (gains, delays, …) calculated by the tools
- Consistency checking + dependent parameters adjustment (filters, cascaded loops)

Using

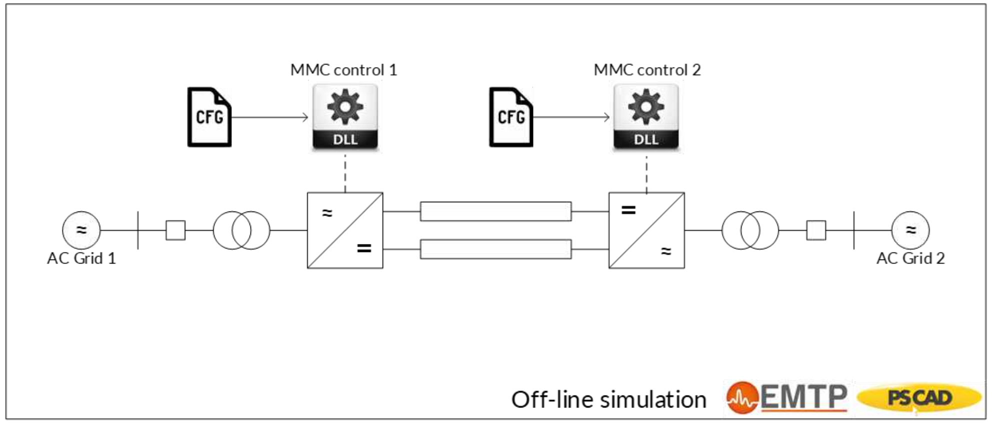
- Vendor initial tuning
- Integrator global parameter adjustment for IOP issues

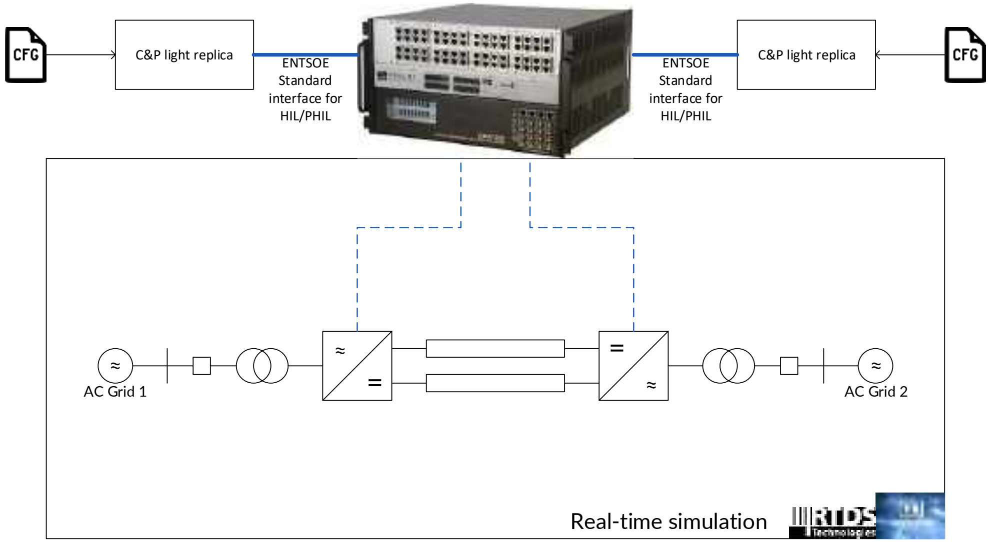
MMC control architecture options

Option 2: Vendor in charge of all control, some functions accessible to the integrator

Test facilities

- **Converter model**
  - Average good enough for IOP issues
  - Model shared between vendors and integrator
- **Converter control**
  - Offline/SIL Converter control
    - **Provided by vendors**
    - **Black-box: Dynamic Link Library, User-Coded Model, Functional Mock-up Unit/Interface**
  - HIL
    - ➔ C&P *light* replica
    - **interfaced at inner loop level (average model level)**
    - **Lower investment**
  - Parameters from configuration tools





MMC control architecture options

Option 2: Vendor in charge of all control, some functions accessible to the integrator

Pros

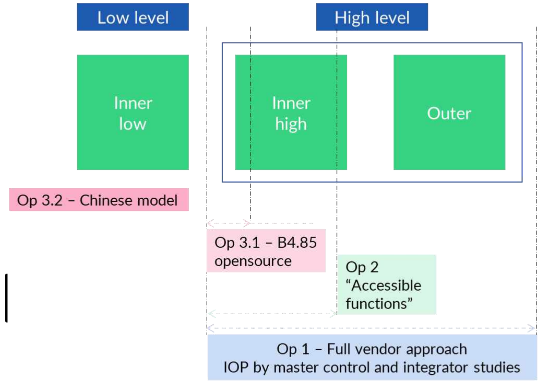
- Not so far from actual organization ➔ Simple & faster
- Optimized implementation
- Optimized software/hardware
- Vendor expertise
- Integrator needs taken into account ➔ integrator tuning

Cons

- First approach to solve interoperability issues but perhaps not sufficent (limited paramaters)
- Wrong tuning without borders
- Responsibilities vendors/integrators not clear
- Vendor IP (reverse engineering)

MMC control architecture options

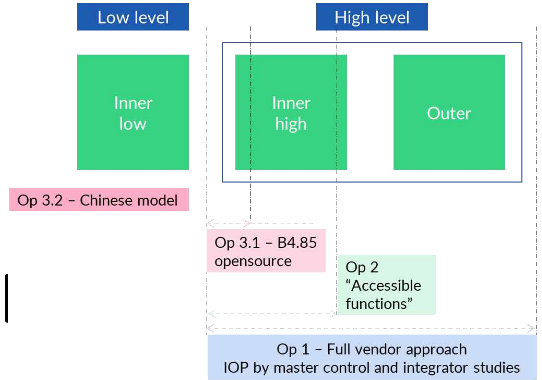
Option 3: Vendor in charge of low level (inner low control), integrator in charge of high level (inner high and outer control



- **High level control ➔ integrator**
  - Requirements, design and implementation
  - Open-source or not
- **Low level ➔ vendor**
  - Closed (black-boxed)
- **Interoperability issues completely solved at integrator level and taken into account from the beginning of the design**

MMC control architecture options

Option 3: Vendor in charge of low level (inner low control), integrator in charge of high level (inner high and outer control



Option 3.1 - Open-source case

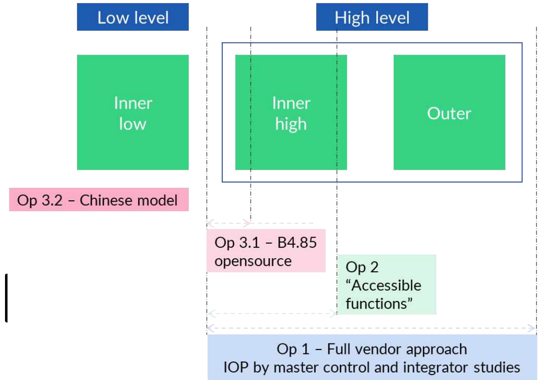
- Cigré WG B4.85
- Innovation should not be limited
- Main locks ➔ licensing model and IP
  - **How mix close and open source?**
  - **How integrate IP?**
  - **Which kind of open-source license ?**

Cigré WG B4.85 scope

- Convenor: Staffan Norrga
- Time schedule: 2020-2023
- Performance requirements
- Signal exchange / communication
- Suitable sectioning of the protection and control software into upper level and lower-level controls (incl. interfaces)
- C&P software
  - **Border(s) between open and proprietary controls**
  - **Requirements**
  - **Open-source software licenses**
- Verification approaches and tools
- Commercial aspects

MMC control architecture options

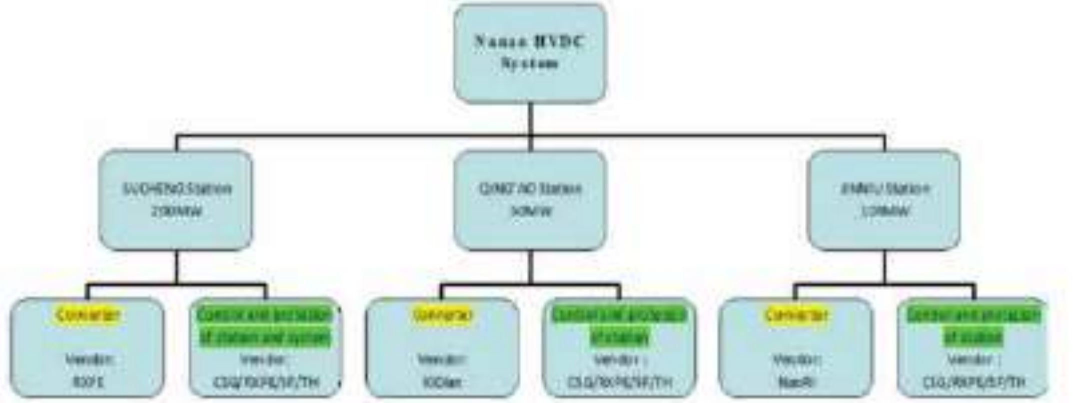
Option 3: Vendor in charge of low level (inner low control), integrator in charge of high level (inner high and outer control



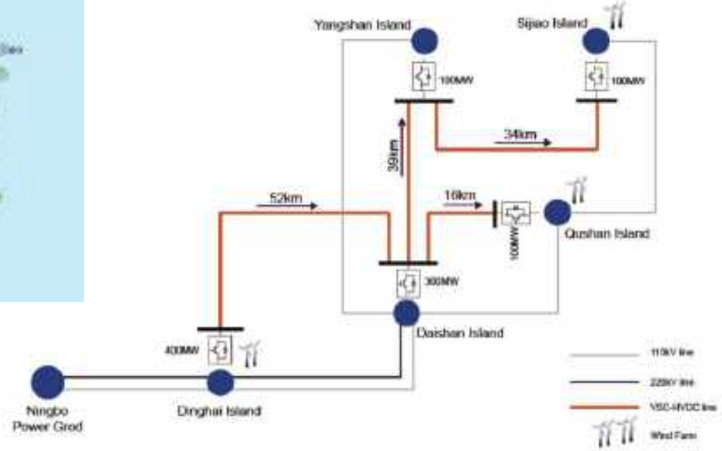
Option 3.2 – Chinese model case

Leader in MTDC development

- **2 operational MTDC**
- **3T, Nan'ao**
  - *China Southern Grid (CSG)*
  - *Multivendor*
  - *SEPRI (Electric Power Research Institute, China Southern Power Grid) technically responsible for the entire project*



- **5T, Zhoushan**
  - *State Grid Corporation of China (SGC)*
  - *Studies: Zhejiang Electric Power Design Institute (Energy China) + Zhejiang Electric Power Company + other companies*
  - *Control strategy: Zhejiang Electric Power Co. + NR Electric*
  - *C&P hardware: NR Electric*



MMC control architecture options

Option 3: Vendor in charge of low level (inner low control), integrator in charge of high level (inner high and outer control)

- **Option 3.2 – Chinese model case**
  - TSO + government ➔ integrator
  - Coordination and management
  - TSO, vendors and academics association for C&P design, implementation and test
  - Success factors
    - **Chinese policy that promotes local industry**
    - **The Chinese TSOs are big companies. They have dedicated groups for HVDC project**

MMC control architecture options

Option 3: Vendor in charge of low level (inner low control), integrator in charge of high level (inner high and outer control)

Pros

- Open-source = the best way to share the control and avoid IOP issues
- Integrator =TSO: the best coordination
- All control done by the integrator, or a consortium (TSO, vendor, academic)

Cons

- Open-source
  - Licence and IP to be fine managed
  - Perhaps a lock to innovation
- Limited role for the vendor and loose of expertise by the vendors, except with consortium

MMC control architecture options

Comparison

	Option 1	Option 2	Option 3
	Full vendor	Accessible functions	Vendor=low Integrator=high
Integrator possibilities / MTDC coordination	☹️☹️	😐😐	🙂🙂
Distance from current development	🙂	🙂	😐
Control tuning	😐	😐	🙂
Conversion optimization	🙂	😐	😐
Control implementation	🙂	🙂	😐
IP/licensing issues (Design phase)#1	🙂	😐	😐
IP issues during investigation & validation#2	☹️	☹️	🙂

Issue #1: to preserve vendors secret know-how
Issue #2: to avoid harmful IP infringement investigation process

MMC control architecture options

Comparison

	Option 1	Option 2	Option 3
	Full vendor	Accessible functions	Vendor=low Integrator=high
Integrator possibilities / MTDC coordination	😞😞	😐😐	🙂🙂
Distance from current development	🙂	🙂	
Control tuning	😐	😐	🙂
Conversion optimization	🙂	😐	😐
Control implementation	🙂	🙂	😐
IP/licensing issues (Design phase)#1	🙂	😐	😐
IP issues during investigation & validation#2	😞	😞	🙂

Strong public European integrator
Strong involvement of station vendors
➔ not so far from Chinese model

Issue #1: to preserve vendors secret know-how
Issue #2: to avoid harmful IP infringement investigation process

Wrap-up

Sébastien Silvant

Wrap-up

- **International alignment on project and system compatibility parameters needed urgently**
  - Future proof new HVDC links by enabling their expandability
  - Coordination of primary technical parameters and relatively small anticipatory investments today can avoid large CAPEX in the future

- **Development of formal technical and operational rules of engagement should be initiated**
  - HVDC system operational guidelines
  - Multi-vendor system integration best practise

- **HVDC system grid code**
  - Challenging to specify requirements at the DC point of connection due to broad range of implementation options
  - Need to pursue efforts towards harmonisation of functional requirements
  - Level of detail of specifications is expected to evolve over time

Wrap-up

- **The role a system integrator has been outlined, one of the options is to create a liable European public (regulated) integrator,**
  - in order to capitalize experience and know how,
  - in order to mutualize risks

- **New additional project stages such as:**
  - a pre-tender qualification phase
  - a preliminary step of full C&P HIL validation before actually building the stations

Wrap-up

- **Coordinated DC Grid Control previously introduced by Best Path and CENELEC:**
  - Emphasis on the importance of such control layer
  - To introduce it on any new HVDC point to point project would favor future system compatibility

- **MMC controls have to be somehow opened and accessible for system integration, to allow tuning and solving of interoperability issues.**
  - Different tradeoffs have been presented.
  - The concept of an MMC control configuration tool has been introduced.
  - Fair licensing of patents could be the solution to keep innovation, competition alive in an open source context.
  - CIGRE WG B4 85 will further elaborate on this topic.

To conclude

- Thank you for your attention

- This webinar is a small step in the long journey

- Feedback is welcome, our door is opened for further discussions