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HVDC-WISE

IAEW High Voltage Equipment & Grids, Digitalization & Energy Economics | RWTH AACHEN UNIVERSITY

Study Committee B4

DC Systems and Power Electronics

2091105

# A classification framework for HVDC-based transmission grid architectures

Sarah Anhaus[1], Patrick Düllmann[1], Lars Osterkamp[1], Robert Dimitrovski [2], Paul McNamara[3], Juan-Carlos Gonzalez[4]

1: RWTH Aachen University, Germany | 2: TenneT TSO GmbH, Germany | 3: EPRI Europe, Ireland | 4: Super Grid Institute, France

## Motivation

- Guidance to estimate risks associated with certain architectures without detailed studies

**Challenges**

- Ensuring system stability and maintaining R&R during disturbances are major challenges in the large-scale integration of RE into the systems
- Existing categorizations for HVDC-based systems predominantly focus on either DC or AC individually

**Research Gap and Problem Statement**

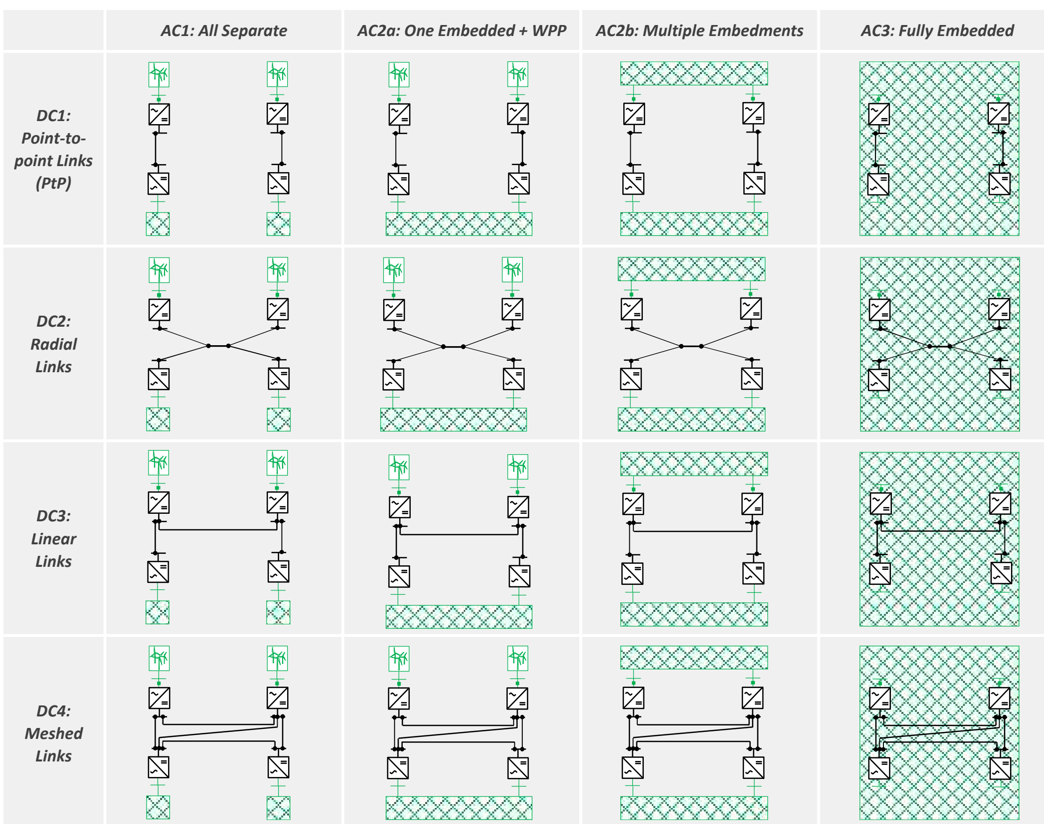
- Gap on HVDC assumes meshed systems without considering practical feasibility
- Planning remains static without accounting for challenges of different DC topologies
- Need for a comprehensive approach that integrates AC/DC to improve planning, design, and operation

## Aim of this Contribution

- Define HVDC-based transmission grid architecture by combining multiple AC / DC configurations
- Focus on AC-side embedment level and DC-side topology to derive necessary technological components and operational strategy

## Classification Methodology

- A 4x4 style matrix is used to classify and analyze various HVDC and AC grid topologies
- AC/DC architecture matrix and embedment levels are generic, no specific AC network characteristics, variations in strength, or specific HVDC configurations
- Extensions could include additional topological classifications incl. DC/DC converters or DC side loads
- Any parameters/properties can be assigned to the AC networks

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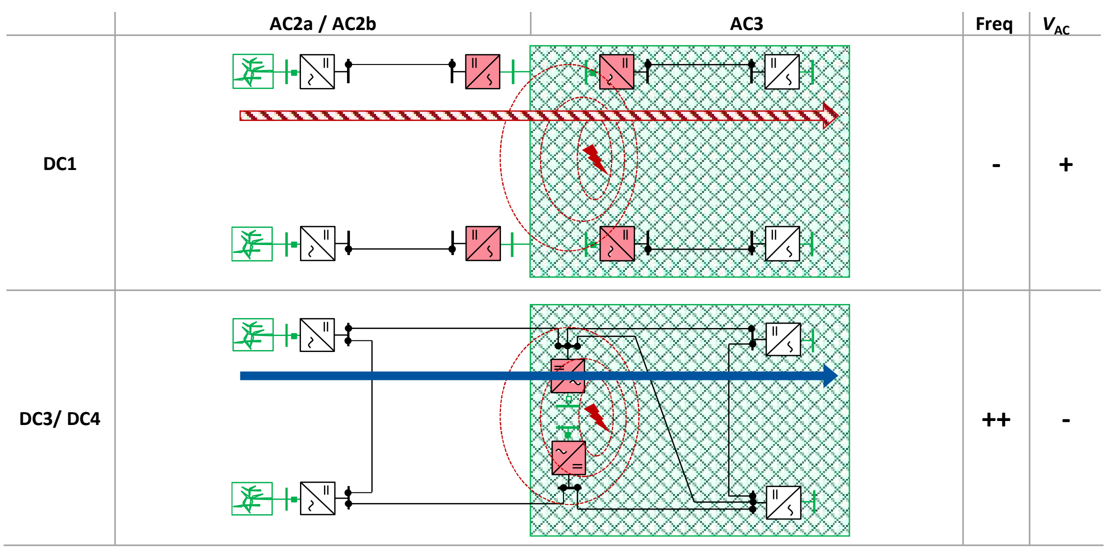
## A Test Scenario Representation

- Qualitative assessment method for evaluating system-level KPIs of different AC/DC architectures, using performance indicators from "--" (weak performance, high risk) to "++" (excellent performance, low risk)
- Example compares KPIs between architecture structure. Key assumptions include for instance quick fault clearance or FRT capability
  - DC1 shows higher risk to frequency stability during faults
  - DC3/4 architecture maintains power transfer, avoiding major events and energy dissipation, though grid support at fault locations is less robust due to fewer converters

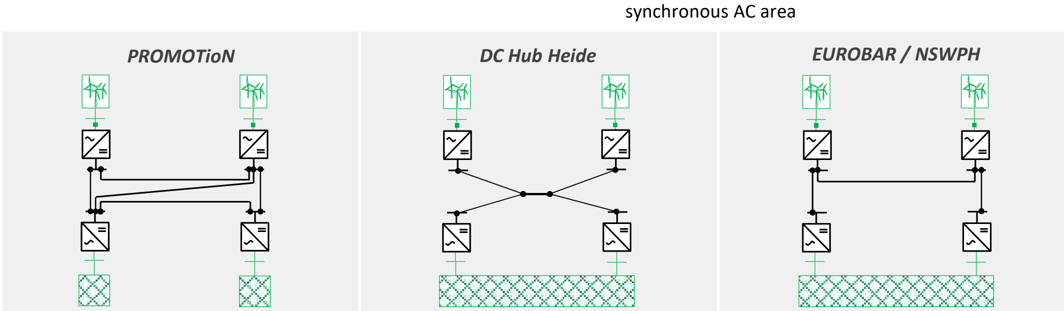



## Real Life Applications

- Proposed methodology can classify MTDC projects in Europe
- Classifications of current project such as PROMOTioN, DC Hub Heide, EUROBAR or North Sea Wind Power Hub

## HVDC-WISE Project Use Cases

- Use Cases for Continental European network, GB network, Multipurpose HVDC grid for offshore wind integration and inter-area trade
- Continental European network: Focus on wide-area HVDC systems integrated within a meshed synchronous AC area

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## Opportunities

**System Planning and System-level Studies**

- MTDC systems (DC2-DC4) enhance reliability and resilience by improving efficiency, active power transfer, and renewable integration
- Higher AC embedment levels (AC2-AC3) facilitate broader grid services deployment, improve N-1 security, and relieve congestion

**Control Concepts**

- HVDC systems enable efficient long-distance power transmission
- Advanced grid services like frequency control, AC voltage support, and grid-forming capabilities

**Protection Functionalities**

- Protection devices like DC CBs, fault-blocking converters or DC/DC converters enhance HVDC system security

## Risks

**System Planning and System-level Studies**

- DC2-DC4 systems requiring N-1 contingency planning and presenting higher complexity
- Chance for DC circuit overloading if no counter-measures are taken for DC3 / DC4 systems (AC1-AC3)

**Control Concepts**

- Potential link losses and control failures are leading to grid instabilities
- Higher in setups like AC2b or AC3, especially with multiple grid-forming VSCs, compared to simpler AC1/DC1 configurations

**Protection Functionalities**

- Increased complexity in MTDC systems raise the risk of network-wide failures
- Impacts crucial services like grid-forming control, especially at higher AC embedment levels (AC3)

| *DC Grid* | *DC1* | | | | *DC2* | | | | *DC3* | | | | *DC4* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *AC Grid* | *AC1* | *AC2a* | *AC2b* | *AC3* | *AC1* | *AC2a* | *AC2b* | *AC3* | *AC1* | *AC2a* | *AC2b* | *AC3* | *AC1* | *AC2a* | *AC2b* | *AC3* |
| *System Planning* | | | | | | | | | | | | | | | | |
| Use of grid services over multiple asynchronous areas | | | | | | | | | | | | | | | | |
| Improve security with more than one connection between areas (synchr./ asynchr.) | | | | | | | | | | | | | | | | |
| Fault may lead to a critical loss of power infeed/export in a single synchronous AC grid | | | | | | | | | | | | | | | | |
| Increased complexity of C&P solutions | | | | | | | | | | | | | | | | |
| *Control Concepts* | | | | | | | | | | | | | | | | |
| Multiple AC embedded VSCs coordinate to enable services as line emulation | | | | | | | | | | | | | | | | |
| Grid-forming capabilities | | | | | | | | | | | | | | | | |
| Potential interaction between converters electrically close | | | | | | | | | | | | | | | | |
| Oscillation risks (triggering protection, spreading oscil.) | | | | | | | | | | | | | | | | |
| *Protection Functionalities* | | | | | | | | | | | | | | | | |
| Use of DC-side Protection | | | | | | | | | | | | | | | | |
| Fault-blocking converters for DC grid protection (NS/PS) | | | | | | | | | | | | | | | | |
| Distance AC line protection | | | | | | | | | | | | | | | | |
| Use of fault separation | | | | | | | | | | | | | | | | |

| *Very Beneficial* | *Beneficial* | *Neutral* | *Risk* | *High Risk* |
|---|---|---|---|---|

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