Smart Grids: High-Voltage Direct-Current (HVDC) Grids

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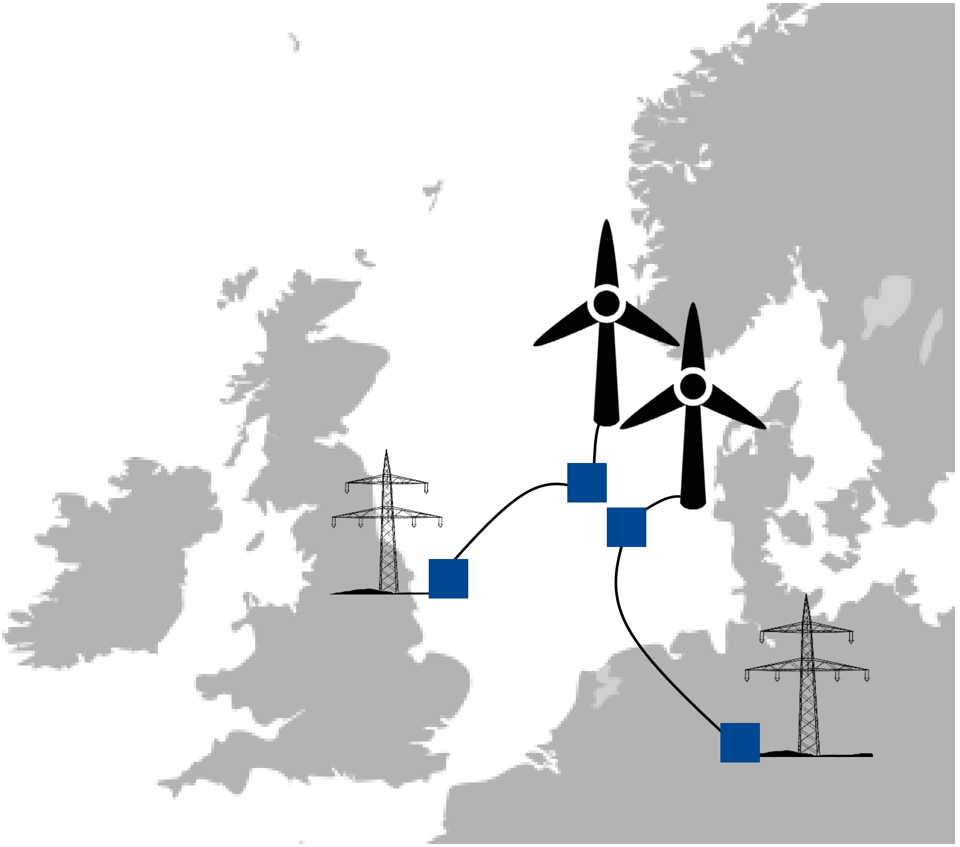
HVDC grids

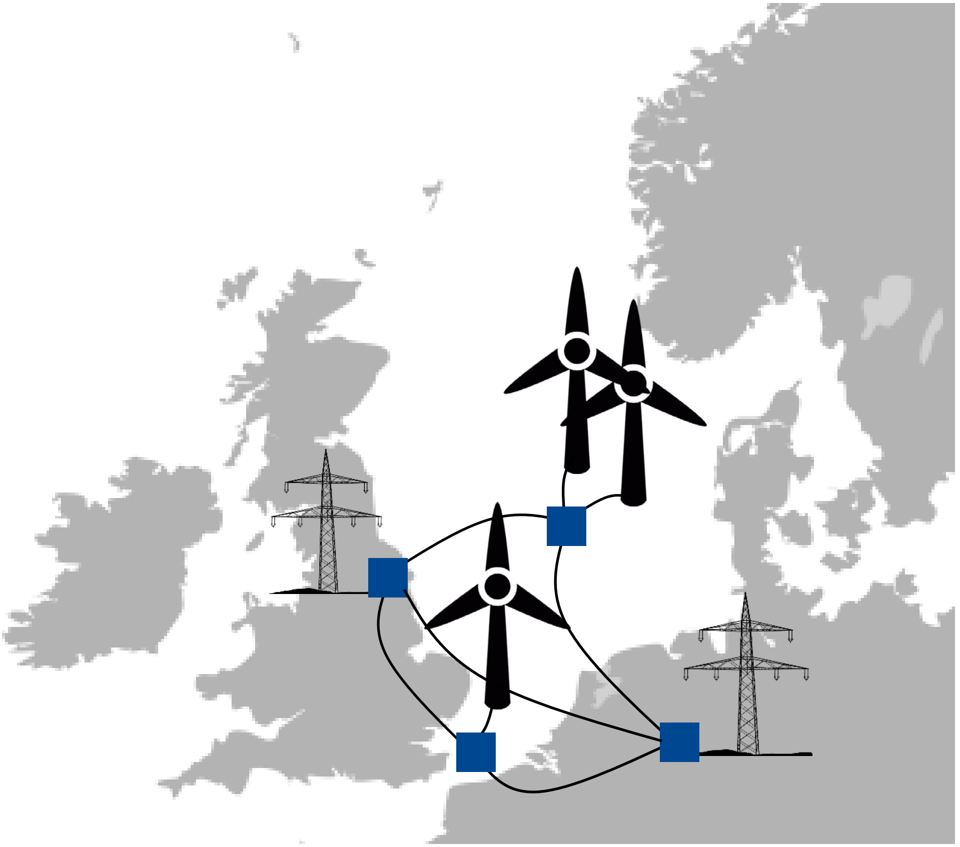
- High-voltage direct-current (HVDC) systems is main technology to connect offshore wind



HVDC grids

- High-voltage direct-current (HVDC) systems is main technology to connect offshore wind

- HVDC grids for cost savings and reliability improvements



Offshore wind turbines with HVDC converter station

Picture: PROMOTioN project / TenneT

HVDC converter station

Picture: PROMOTioN project / TenneT

HVDC converter

- Power Electronic Converter
- Software-defined behavior

Picture: ABB/Hitachi

HVDC across the World (September 2025)

Source www.hvdcworld.com

HVDC - Figures

HVDC in Europe

- Single-vendor point-to-point HVDC established
- First single-vendor 3-terminal
- Multi-terminal & multi-vendor projects ca. 2030

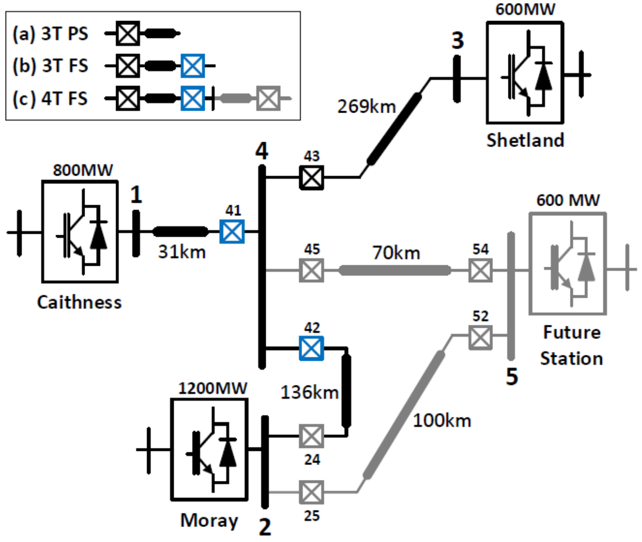
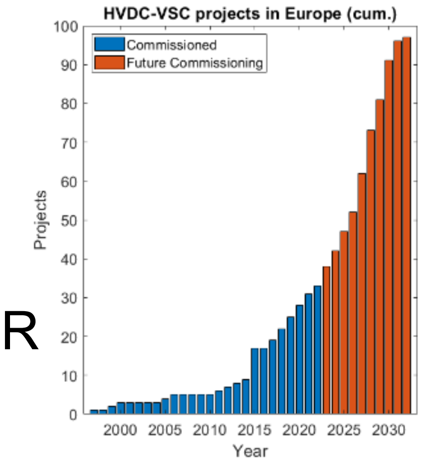


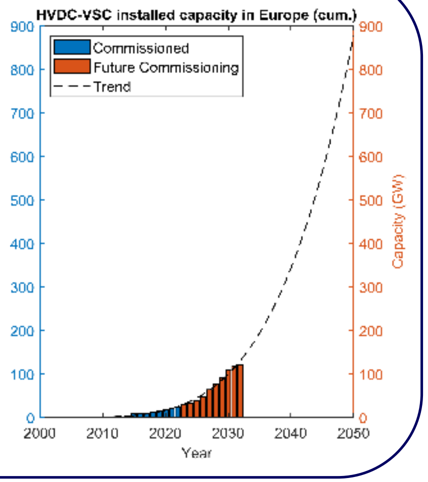
Fig. 1. Caithness-Moray-Shetland case study system; three terminal (3T) and hypothetical four terminal (4T). Hypothetical DC-side protection cases indicated; partially selective (PS) and fully selective (FS).

European offshore wind goals

- Status Quo (2022):
  - 30 GW offshore wind installed capacity in EU + UK
  - 3% of electricity demand covered by offshore wind
- EU targets (2020):
  - 300 GW offshore wind installed capacity by 2050
  - 60 GW by 2030
- Ostend Declaration of North Sea countries (2023)
  - >120 GW offshore wind capacity by 2030
  - >300 GW by 2050

- Massive growth rates
- Hitachi Sweden: largest export order ever 13 BEUR (2023)

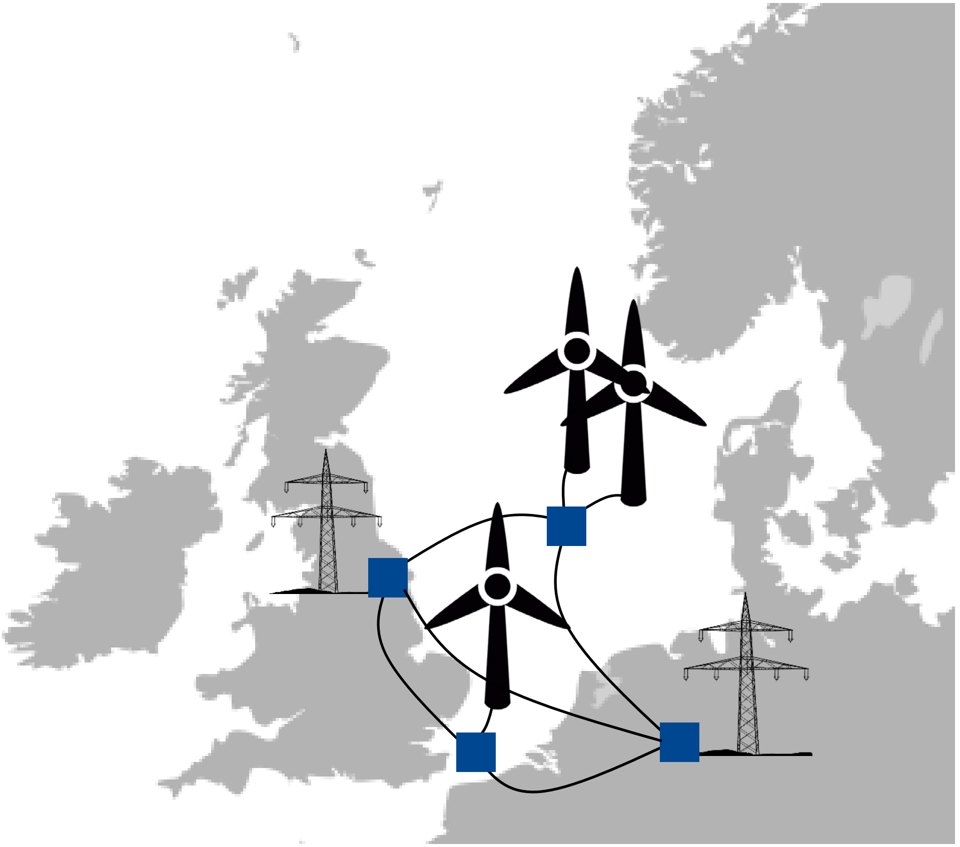




Sources:
J. Cabanas Ramos et al. "Getting Ready for Multi-Vendor and Multi-Terminal HVDC Technology," MDPI Energies 2024
M. Moritz et al., "READY4DC whitepaper: Framing the European energy system" Nov. 2023.

HVDC grids

- High-voltage direct-current (HVDC) systems is main technology to connect offshore wind
- HVDC grids for cost savings and reliability improvements
- 2 big challenges
  - Protection
  - Interoperability



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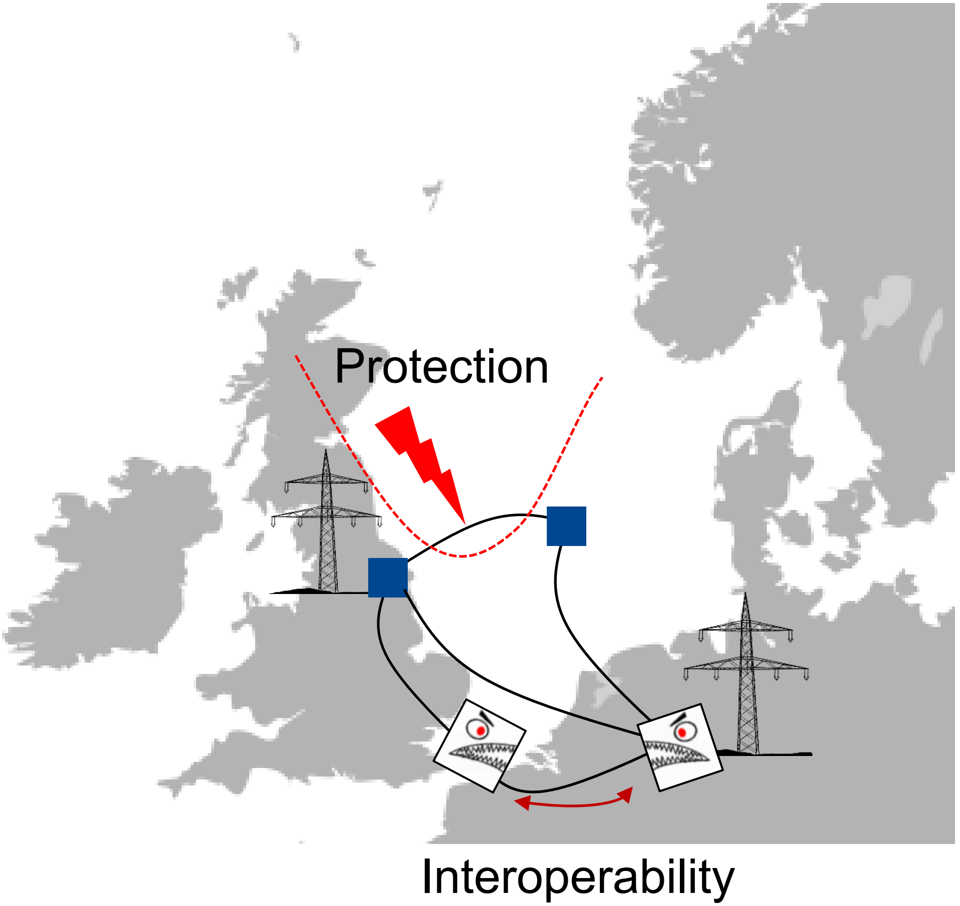
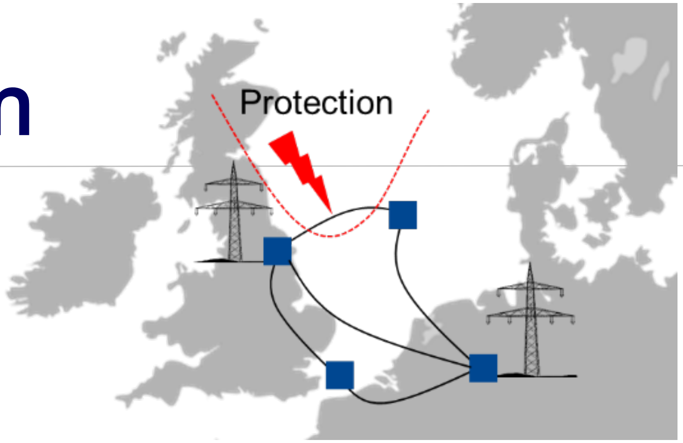
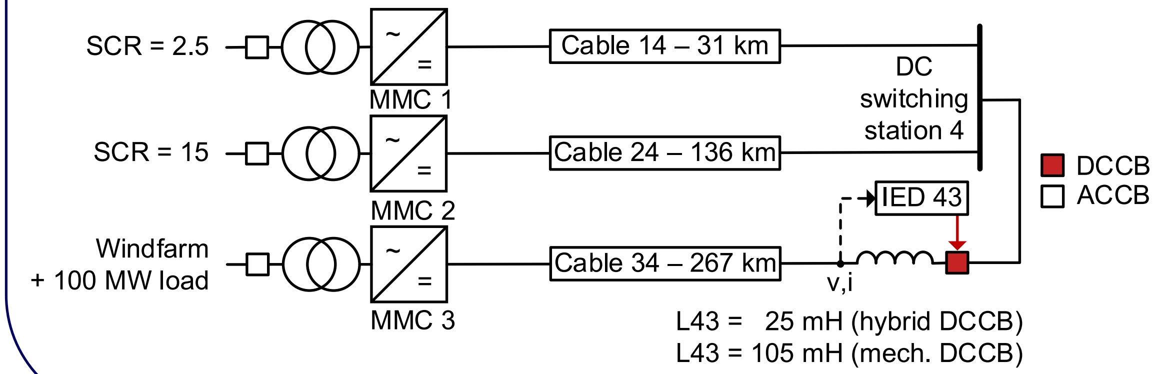


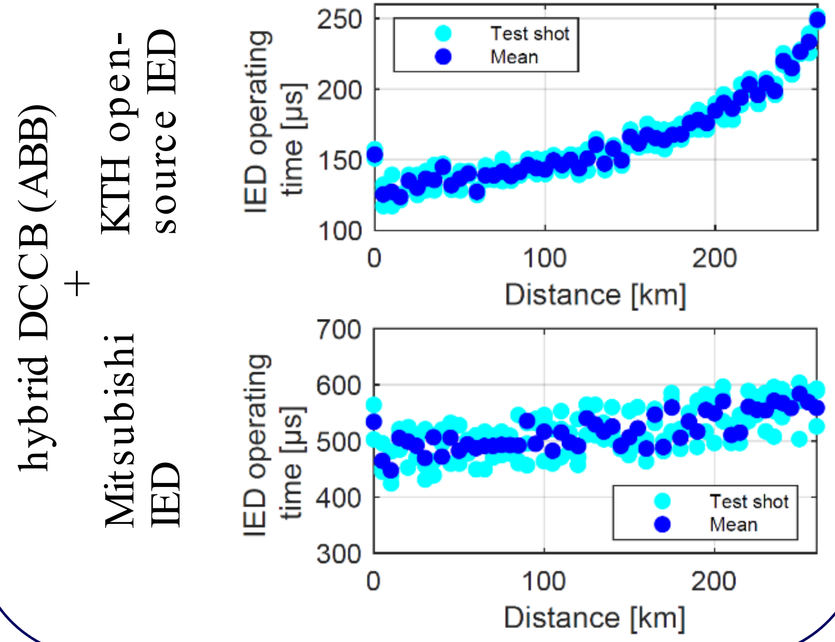
HVDC - Protection



Study example: Partially-selective protection

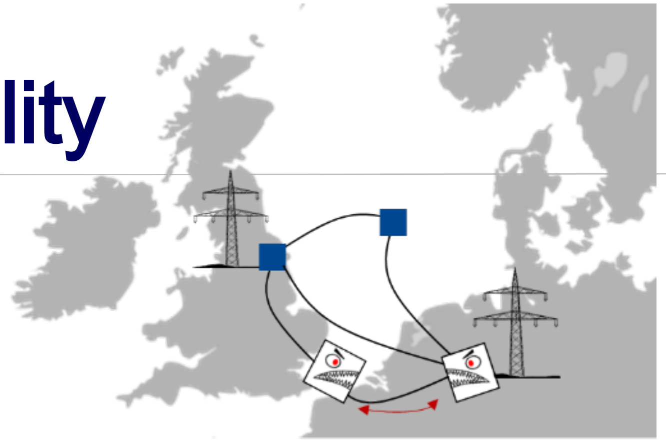
- Hybrid or mechanical DCCB
- KTH open-source or Mitsubishi IED





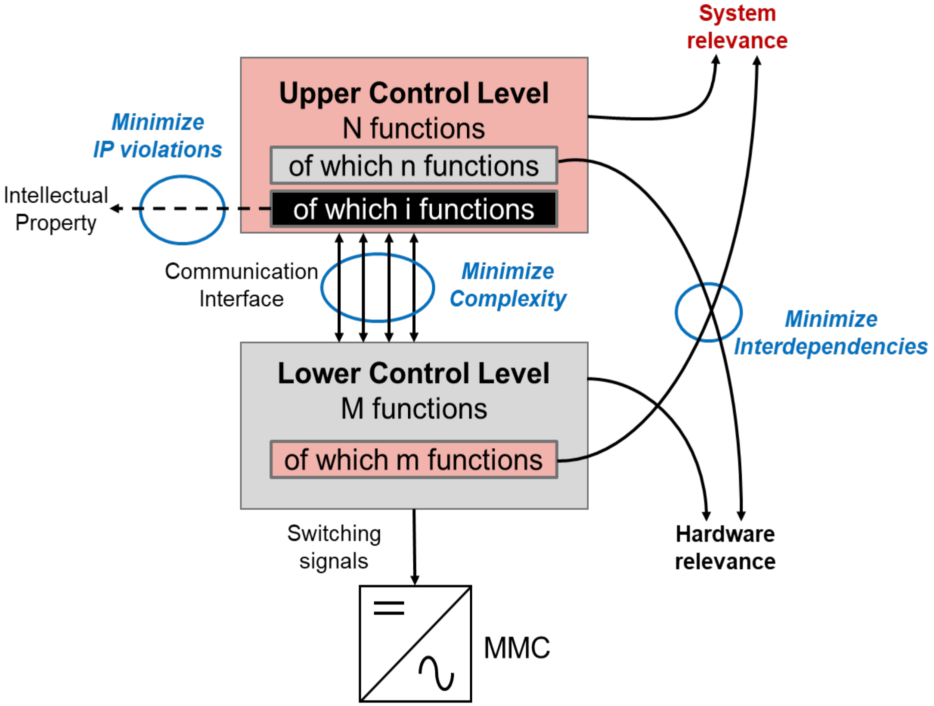
[1] M. Wang et al., "Multi-vendor interoperability tests of IEDs for HVDC grid protection," in *IET DPSP*, Liverpool, 2020.

HVDC - Interoperability



Interoperability

- Upper-level C&P functions are **open** for interoperability / adaptation to future grid changes
- Low-level C&P functions with vendor-specific IP are **black-boxed**



- Open questions in
  - HVDC control
  - HVDC protection
  - Modularized Systems
  - Expanding Systems
  - Decouple SW and HW?