Study Committee B4

DC Systems and Power Electronics

Paper ID 11087

European offshore grid: On protection system design for radial bipolar multi-terminal HVDC networks

Patrick Düllmann[1], Christina Brantl[1], Philipp Tünnerhoff[2], Philipp Ruffing[2], Albert Moser[1]

1: RWTH Aachen University, Aachen, Germany | 2: Amprion GmbH, Dortmund, Germany

Motivation: Integrate offshore wind

- Strong increase of offshore wind farms (OWFs) to be connected to existing AC grids via HVDC technology

Technological changes in HVDC connection systems:

- Sym. monopole → **Bipole with DMR**
- Point-to-point → **multi-terminal networks** (step-wise, radial DC-side interconnection)

Challenges and degrees of freedom:

- (De-)**Coupling of P & N pole** of bipole system
- **Protection** in case of **DC faults**: Limiting the temporary power loss towards the AC grid

Research gap and problem statement:

- Decisions made **today** will affect the **future** development of multi-terminal HVDC systems
- Variety of **DC protection strategies** proposed, but no operational experience in Europe
- No comprehensive **DC fault study** of bipolar multi-terminal systems considering OWFs

Aim of this contribution

- Analyse the behaviour of **bipolar offshore multi-terminal HVDC** systems under **DC fault** conditions
- Study the **impact** and **interdependencies** between **operational concepts and DC protection**
- Reveal challenges with regard to **DC fault recovery**

Investigation Framework

- **HVDC:** 2-GW bipolar, cabled HVDC links at 525 kV
  - Converter technology: half-bridge MMC
  - Radial connection to a 4-terminal DC system
- **Offshore**: 66-kV string-based offshore windfarm with aggregated wind-turbines (fully converter coupled)
  - Frequency-sensitive control for curtailment
  - Different wind power infeed levels analysed
- **Onshore:** Continental European Grid (Thevenin)
  - Maximum allowed power loss: 3 GW

Methodology & Varied Parameters

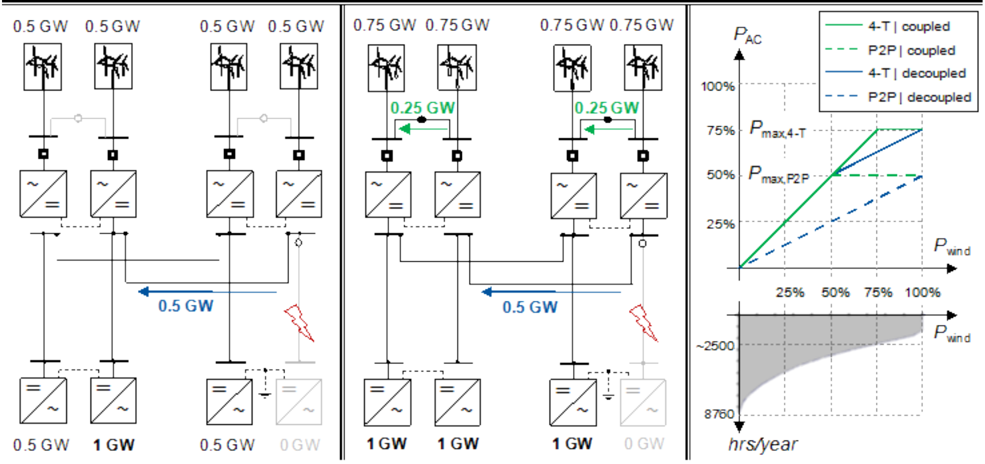
1. **Conceptual analysis**
2. **EMT simulations (type-4 MMC models, PSCAD™)**

Considered time frames / time horizons:

- Between fault inception & fault clearing (temporary)
- After fault clearing (inherent post-fault / recovery)
- After system reconfiguration (long-term state)

Varied impact factors

- **Offshore AC side coupling between P and N pole** (Disconnectors between offshore AC busbars of P and N pole are opened or closed)
- **DC-side protection**: Non-, partially, and fully selective (use of **DC circuit breakers** for the latter two)



cigre PARIS 2022

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

Study Committee B4

DC Systems and Power Electronics

Paper ID 11087

European offshore grid: On protection system design for radial bipolar multi-terminal HVDC networks

Patrick Düllmann[1], Christina Brantl[1], Philipp Tünnerhoff[2], Philipp Ruffing[2], Albert Moser[1]

1: RWTH Aachen University, Aachen, Germany | 2: Amprion GmbH, Dortmund, Germany

Bipole HVDC: Impact of pole coupling

Decoupled offshore AC busbars ("AC decoupled")

- Separated voltage control for P and N pole (U/f ctrl.)
- No interaction via offshore AC side in case of faults
- ➢ **Reduced post-fault availability**

Coupled offshore AC busbars ("AC coupled")

- Control challenge: "grid forming" with load sharing and fast wind power curtailment after DC faults
- DC fault leads to AC-side voltage sag / fault current → increased temporary power loss seen onshore
- ➢ **Higher (full) post-fault transmission capacity**

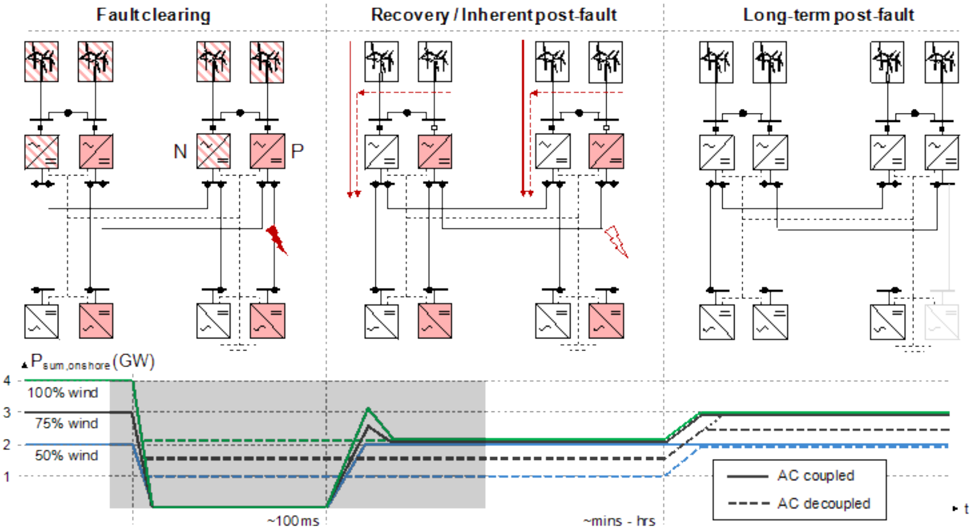
Non-selective protection

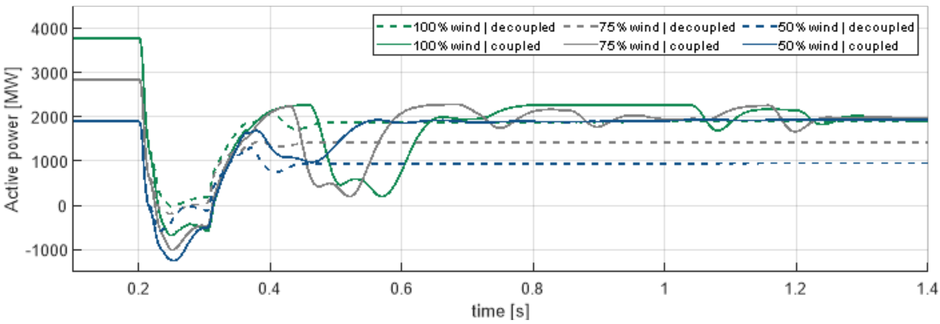
Fault clearing and maximum onshore power loss

- Healthy DC pole remains in normal operation
- **Maximum temporary power loss is larger than 3 GW**
  - Coupled: up to 5 GW; decoupled: 4 GW
  - Additional power loss due to onshore AC fault current infeed trough blocked HB-MMC

Challenges during system recovery

- AC decoupled: No additional challenges
- AC coupled: Controlled wind power curtailment required → demand for robust control systems





http://www.cigre.org

Study Committee B4

DC Systems and Power Electronics

Paper ID 11087

European offshore grid: On protection system design for radial bipolar multi-terminal HVDC networks

Patrick Düllmann[1], Christina Brantl[1], Philipp Tünnerhoff[2], Philipp Ruffing[2], Albert Moser[1]

1: RWTH Aachen University, Aachen, Germany | 2: Amprion GmbH, Dortmund, Germany

Partially selective protection (top)

Fault clearing, power loss, and system recovery

- Temporary **power loss** can be limited to **< 3 GW**
- Effect of AC pole coupling remains, but is reduced
- Challenges & impact of pole coupling equal non-sel.

Fully selective protection (bottom)

Fault clearing = recovery state (inherent recovery!)

- Temporary power loss can be limited to ca. 1 GW
- No effect of AC pole coupling on DC fault behaviour
- **Risk of DC-side overload** → coordination needed