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Security of Supply and Meshed HVDC grids

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CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

Outline

- Conclusions (Hypothesis)
- Potential of meshed HVDC grids
- Power system operation and control – and security
- Control schemes for multi-terminal HVDC
- Examples (illustrating security aspects related to operation and control)
- Further challenges (technical, operational, regulatory)

Conclusions / Hypothesis

- ***A meshed HVDC grid has the potential to improve security of supply!***
- A multi-terminal HVDC grid in the North Sea can effectively integrate the synchronous interconnections (UK, UCTE and Nordic)
- Can be operated as ONE control area (if desirable)
- Reserves (primary and secondary) can be shared without “technical constraints”
- Fast control and protection will enable network splitting to avoid risk of cascading outages and complete blackouts
- Fully integrate the power markets across the asynchronous areas.

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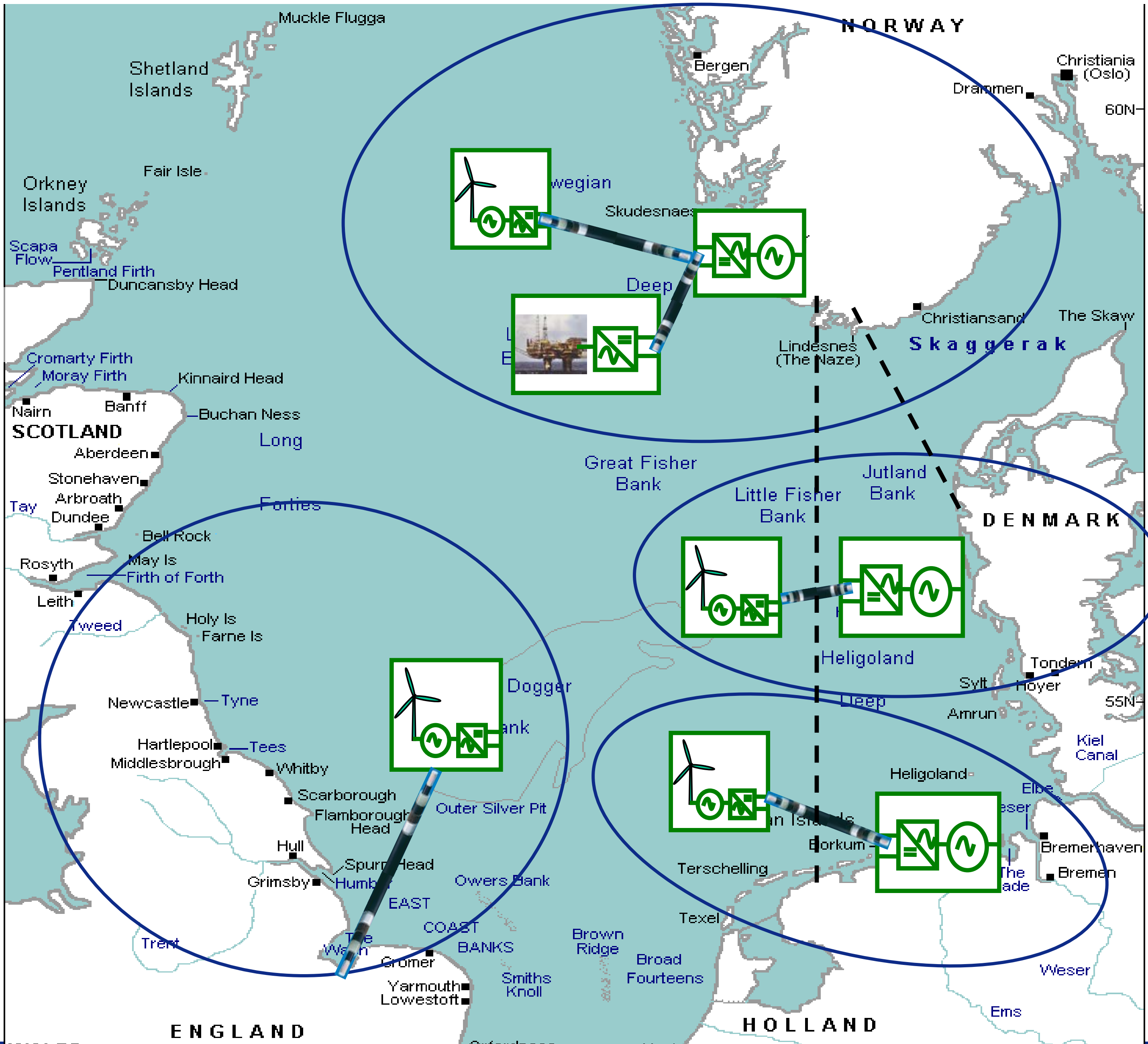
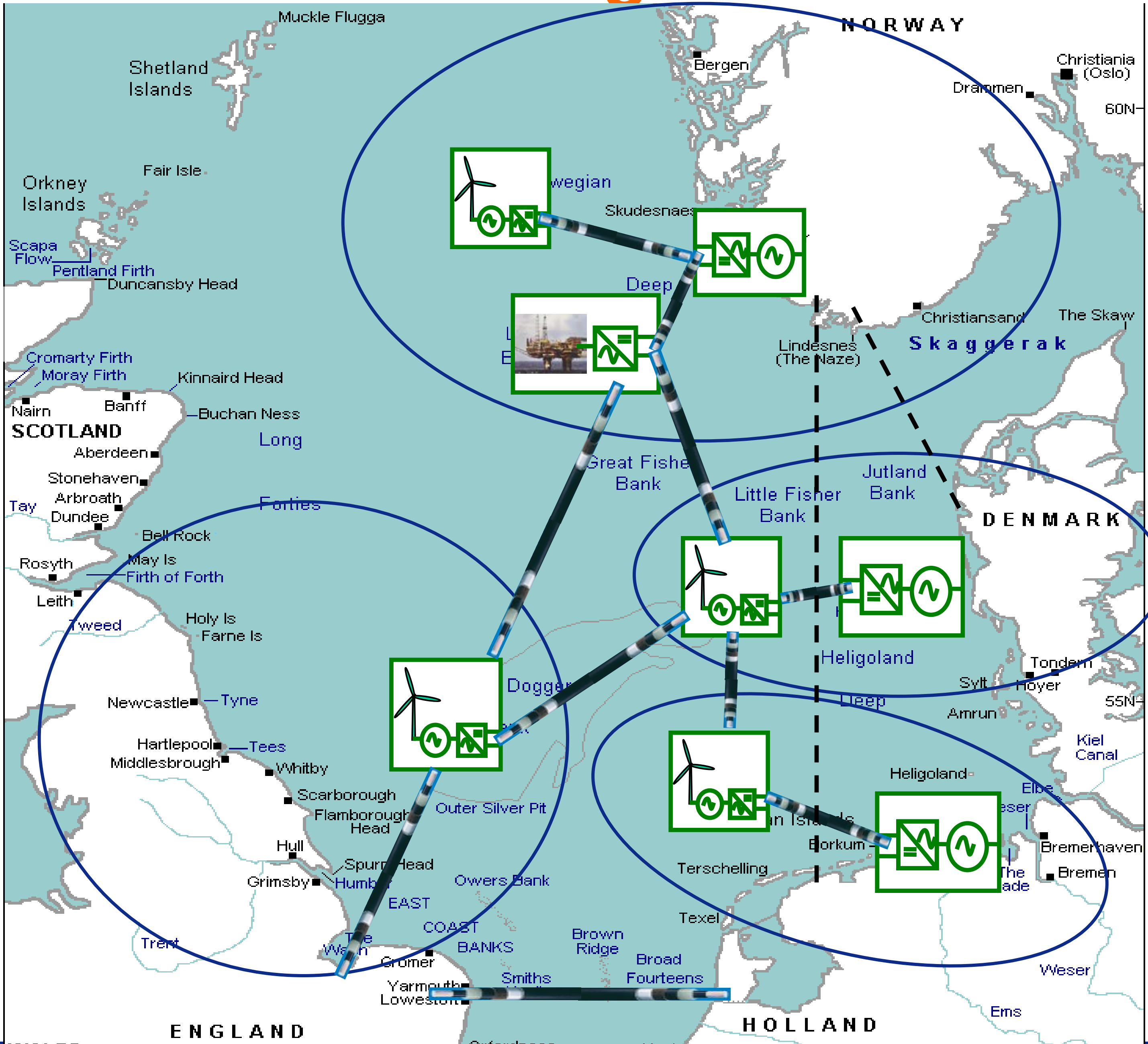
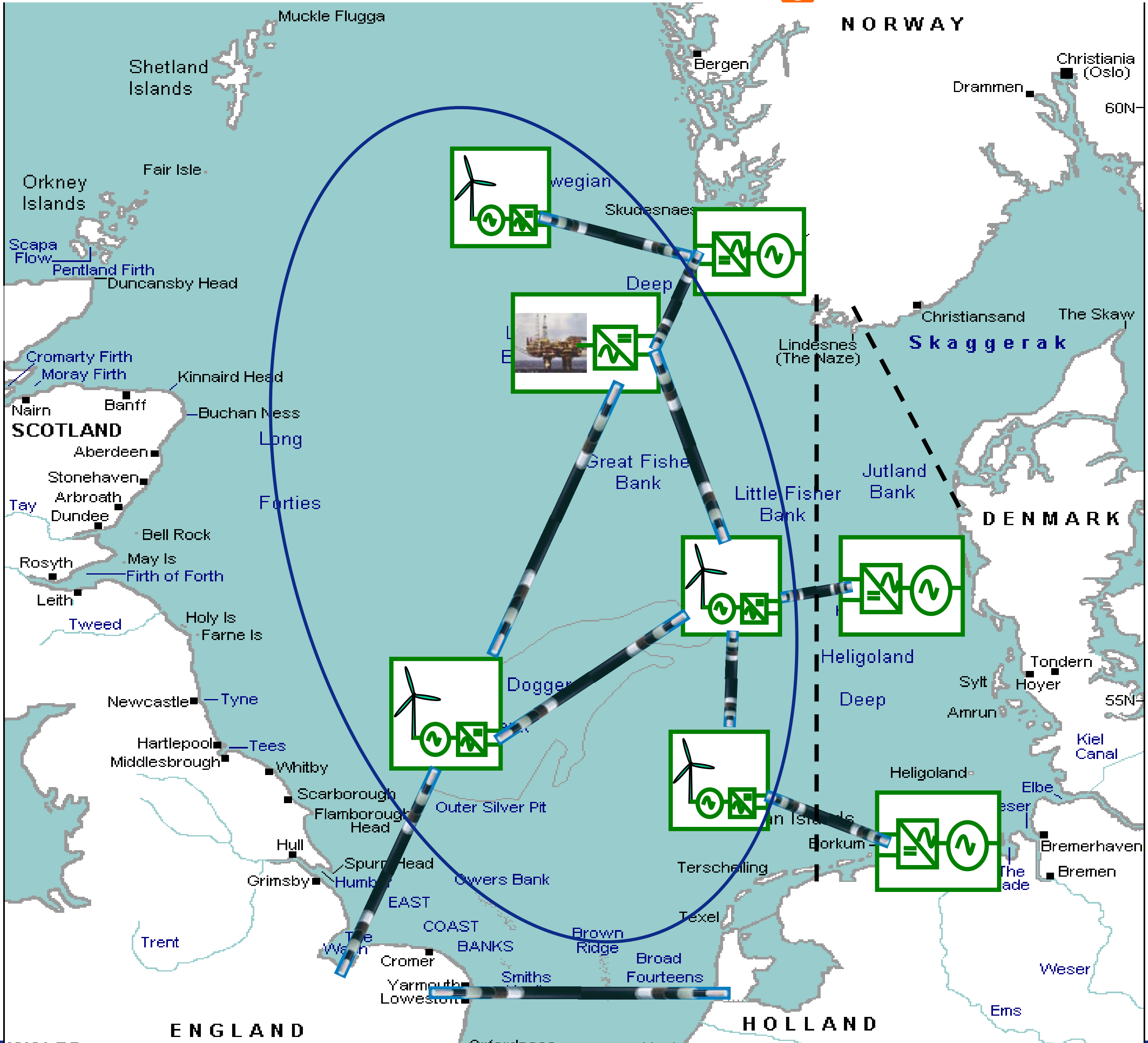
Grid connection



Grid integration



Power market integration



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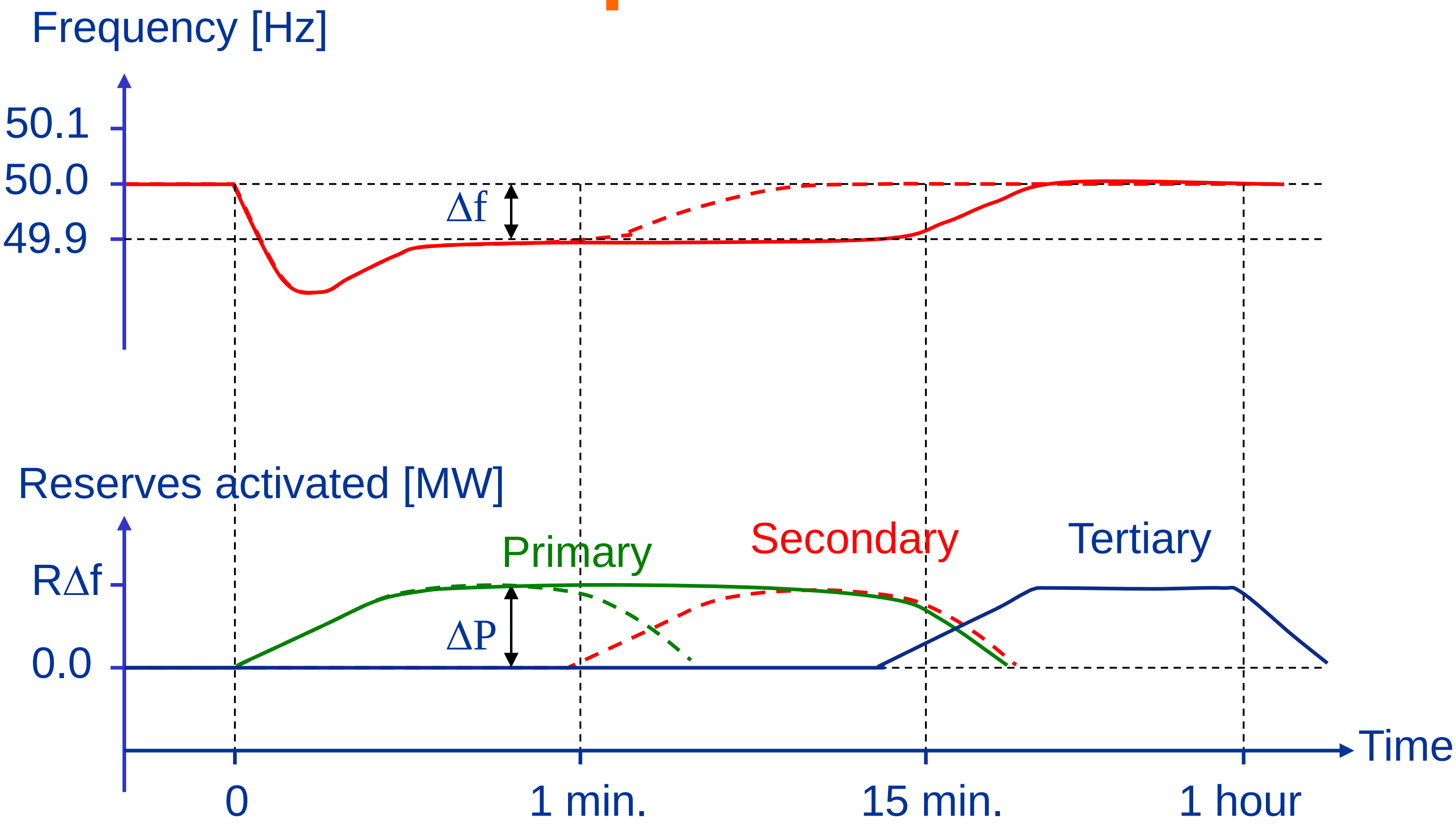
Power system security

- Security standards: Deterministic (N-1) or risk based

- Ability to manage contingencies / outages:
  - Availability of reserves
  - Availability of transmission capacity
  - Stability and control

Control stages in power system operation



System frequency response: $\mathbf{R} = \dfrac{\Delta P}{\Delta f}$ [MW/Hz]

Main challenges in operation and control

- Primary control:
  - Less primary reserves if new generation provide less frequency response
- Secondary control:
  - More need for secondary reserves with more variable generation
- Tertiary control:
  - Benefits with larger control areas and exchange of reserves.

- **New possibilities with an offshore Multi-terminal HVDC grid!**

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Active Power Control in MTDC – Objectives:

Each converter should independently control:

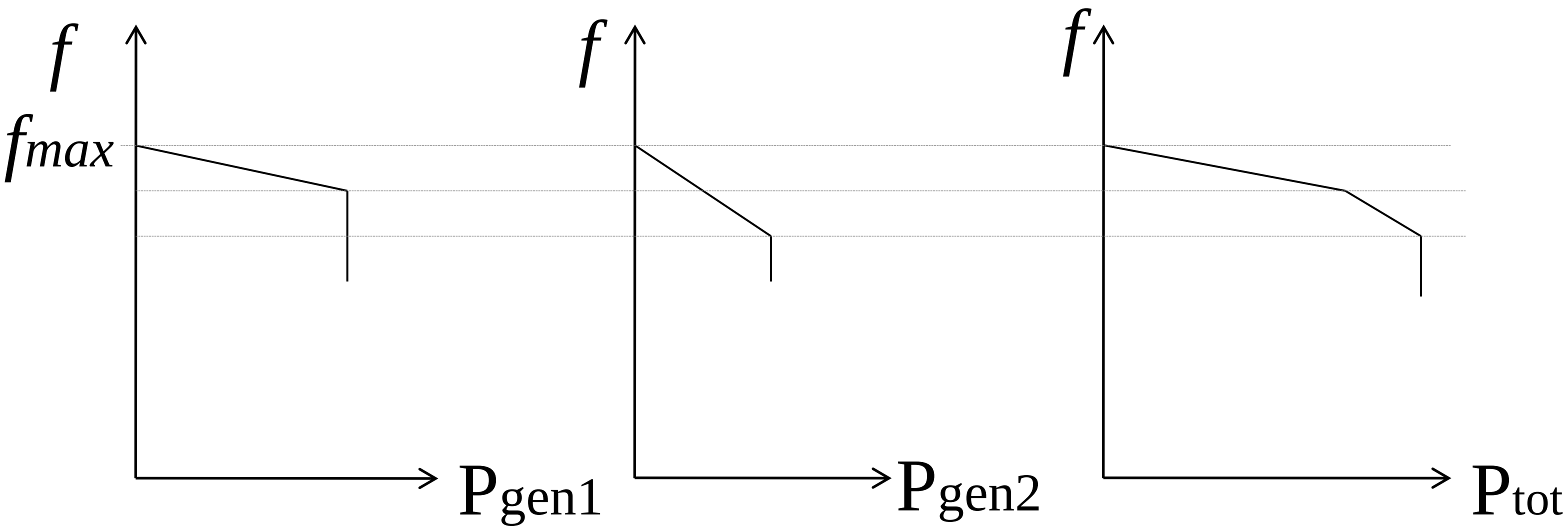
- active power flow
  - as given by the power reference (set point)
- dc bus voltage of the converter
  - to manage the power balance within the DC grid

Controls should also:

- be robust to contingencies
- contribute to the balance of the ac grids
  - contribute to the primary frequency droop control

Power balance control in AC grids:

Traditionally by frequency (speed) droop



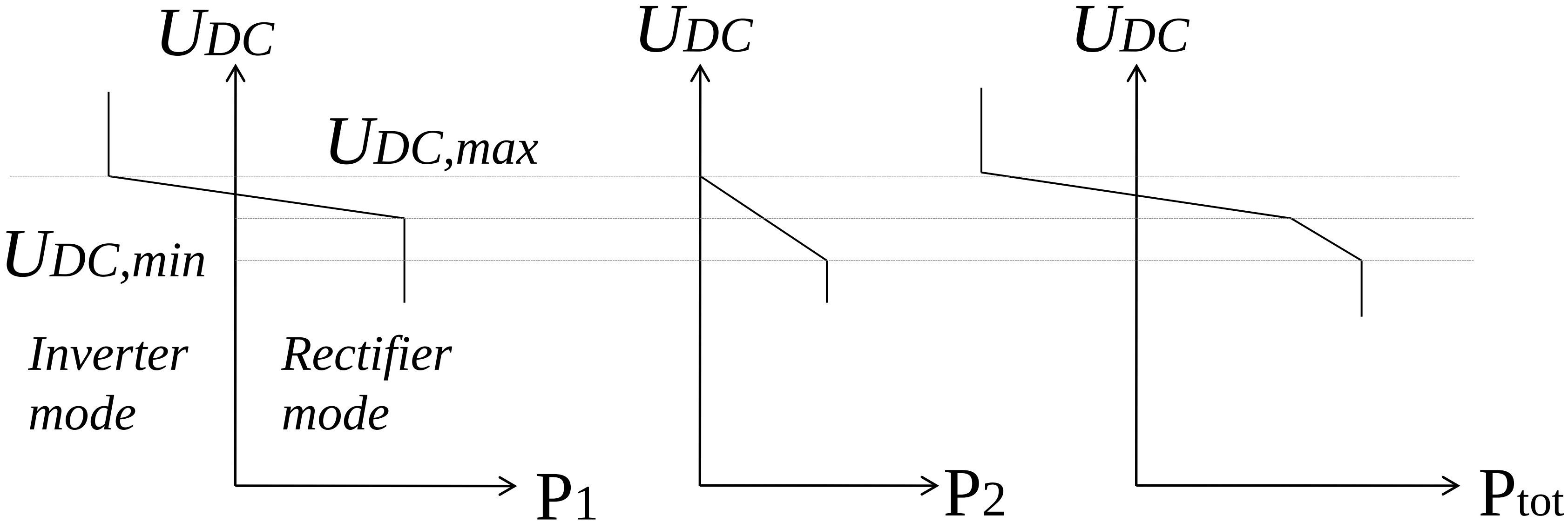
Generation station-1

Generation station-2

Aggregate

Power flow control in DC grid :

achieved by DC voltage droop



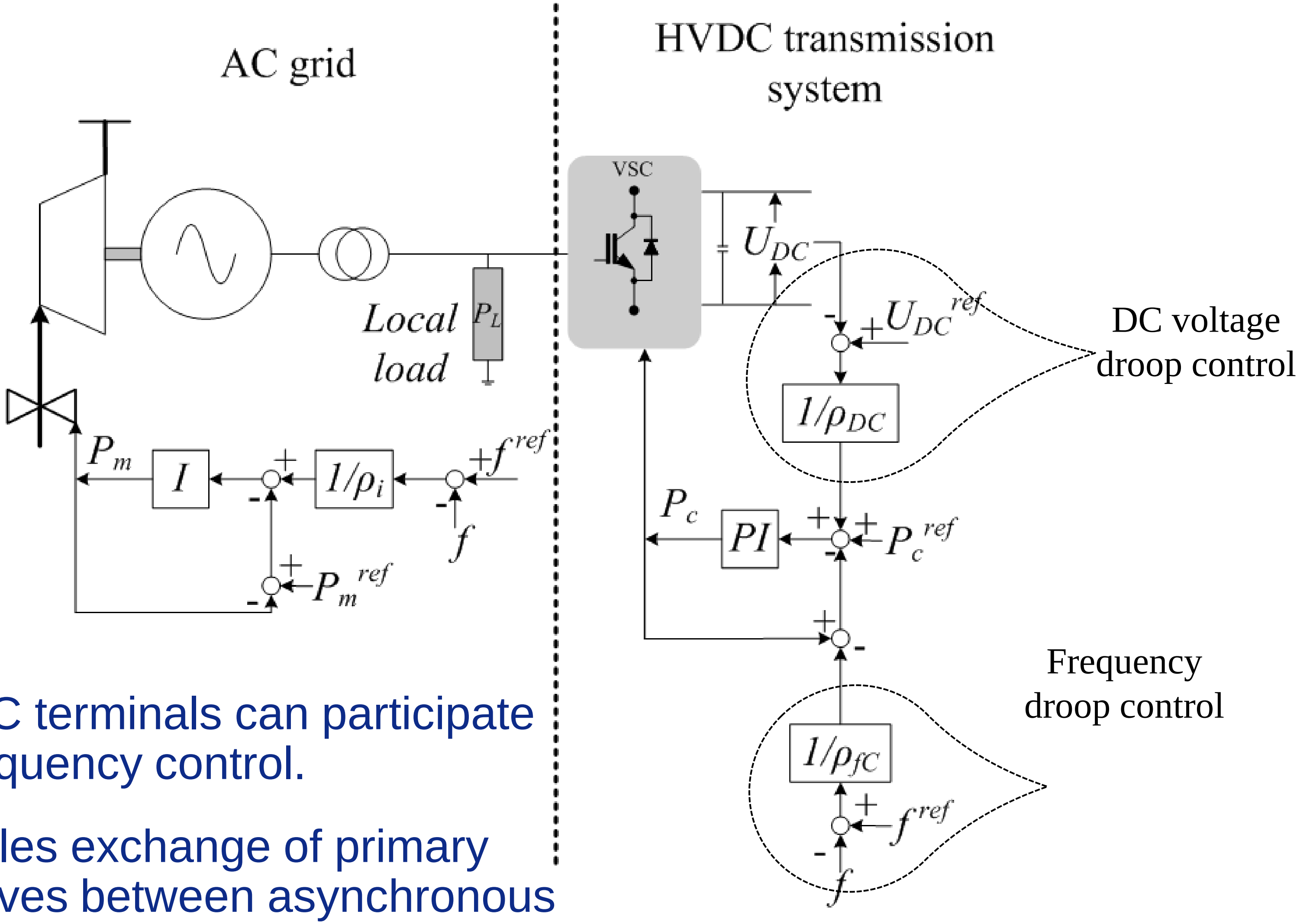
VSC-HVDC station-1

VSC-HVDC station-2

Aggregate

- **No need for communication between terminals**
- **Many converter terminals contribute to dc voltage regulation**
- **DC analogy to distributed *frequency droop control* in AC systems**

HVDC converter control implementation



HVDC terminals can participate in frequency control.

Enables exchange of primary reserves between asynchronous AC grids

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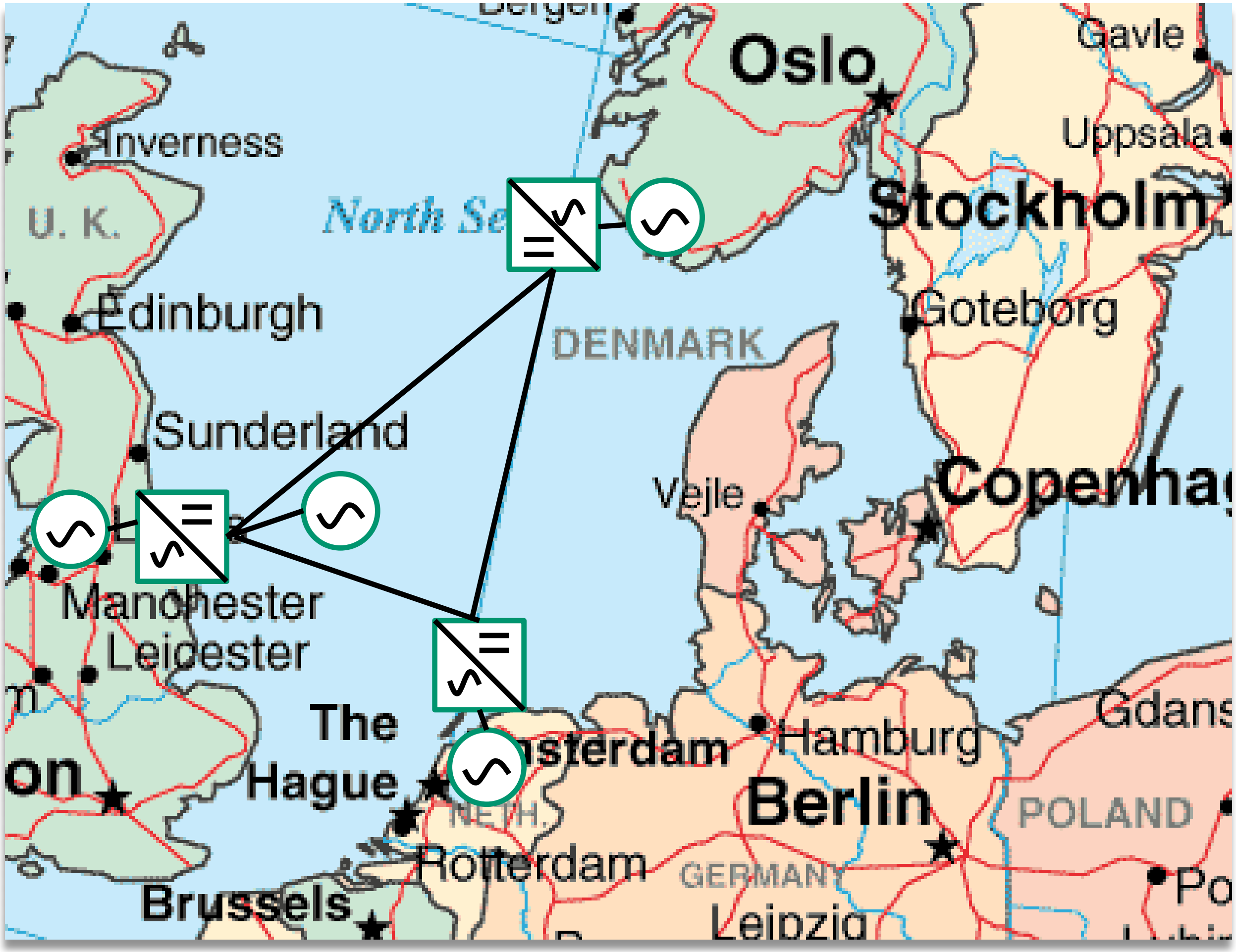
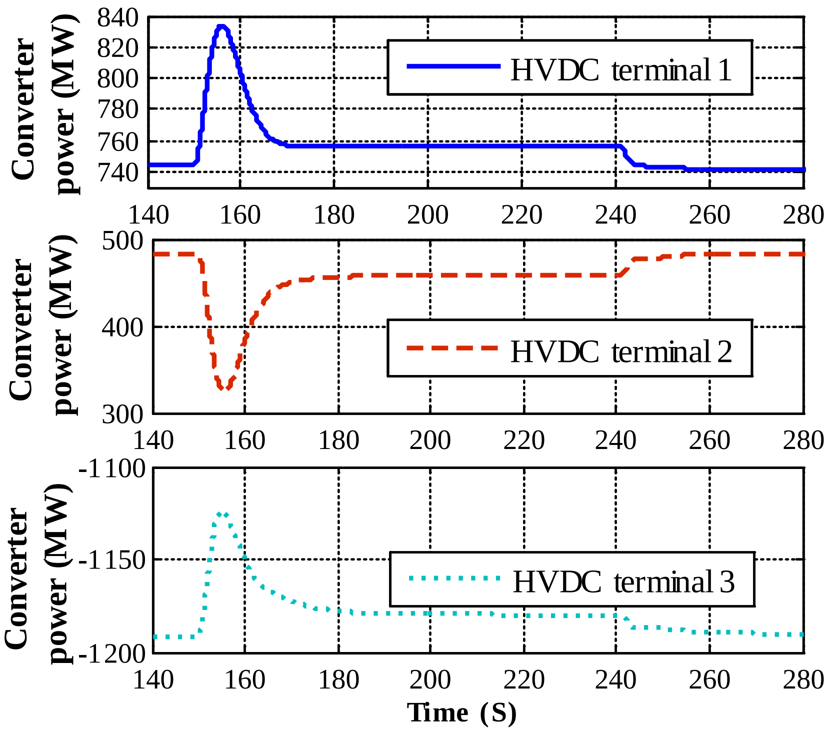
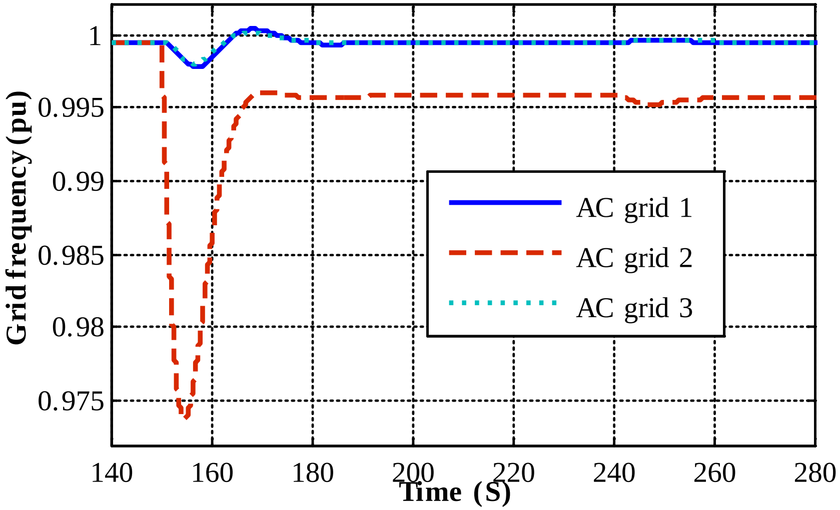
Simulation example

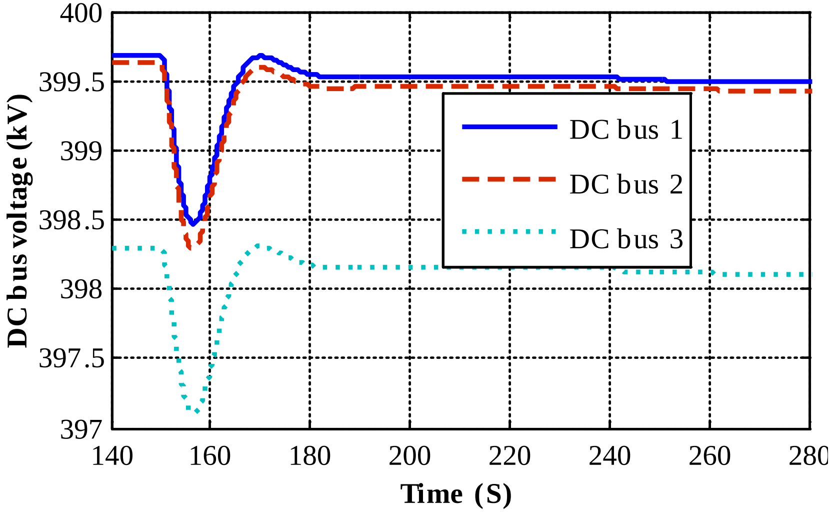


Primary and secondary controls of MTDC system

- **Loss of 1GW generation unit in AC grid-2**
- **MTDC contributes to frequency support**
- **Secondary control activated by changing converter power references to compensate for power flow deviations**







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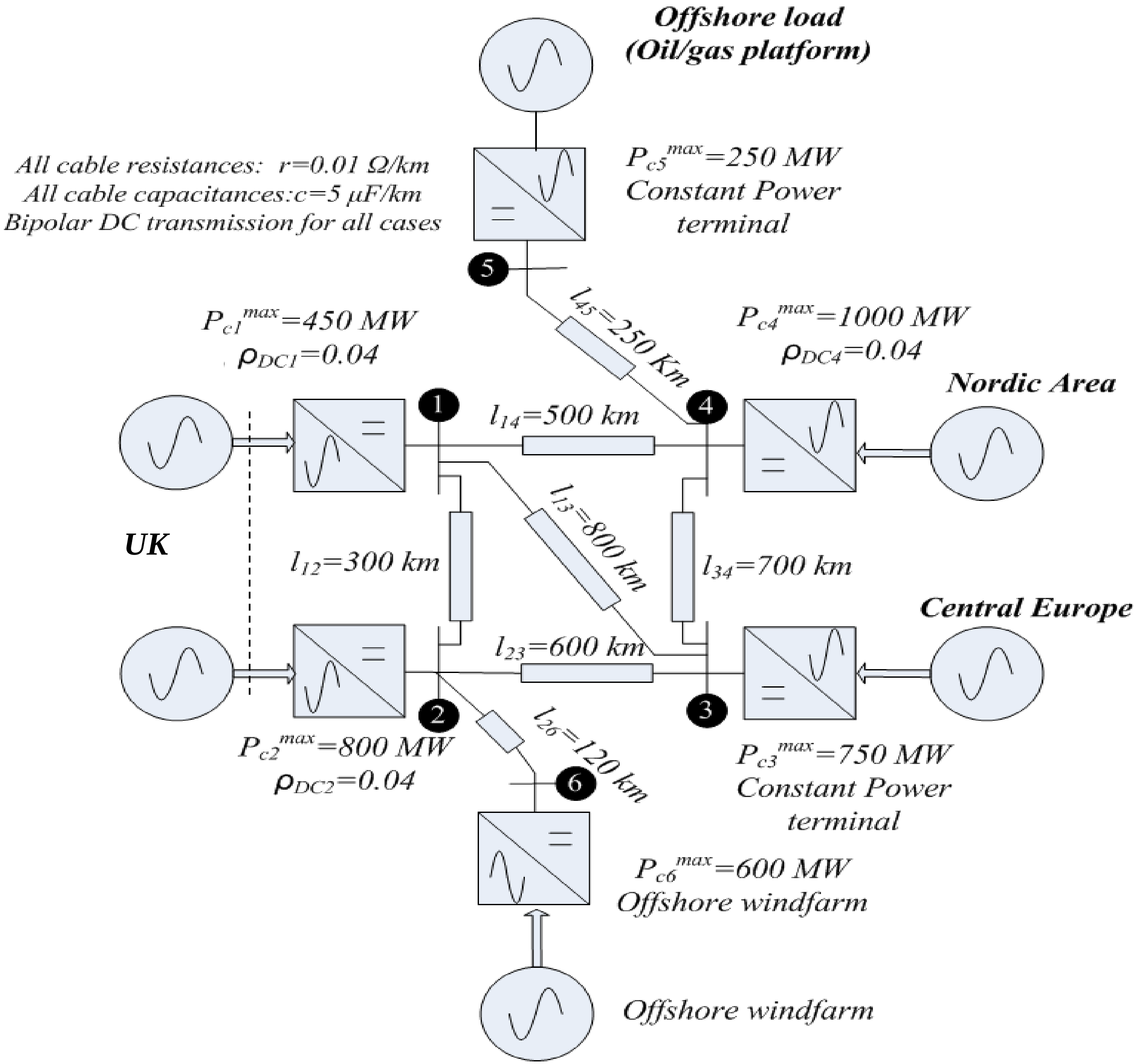
Further challenges

- Technical:
  - DC circuit breakers
  - Protection (selectivity)
  - Converters and Cables
  - Standardisation (different vendors)
- Operational:
  - Who controls what and when?
  - Coordination and collaboration
  - Market design
- Regulatory
  - Harmonisation of security standards and grid codes
  - (Harmonisation of market rules and incentive schemes)

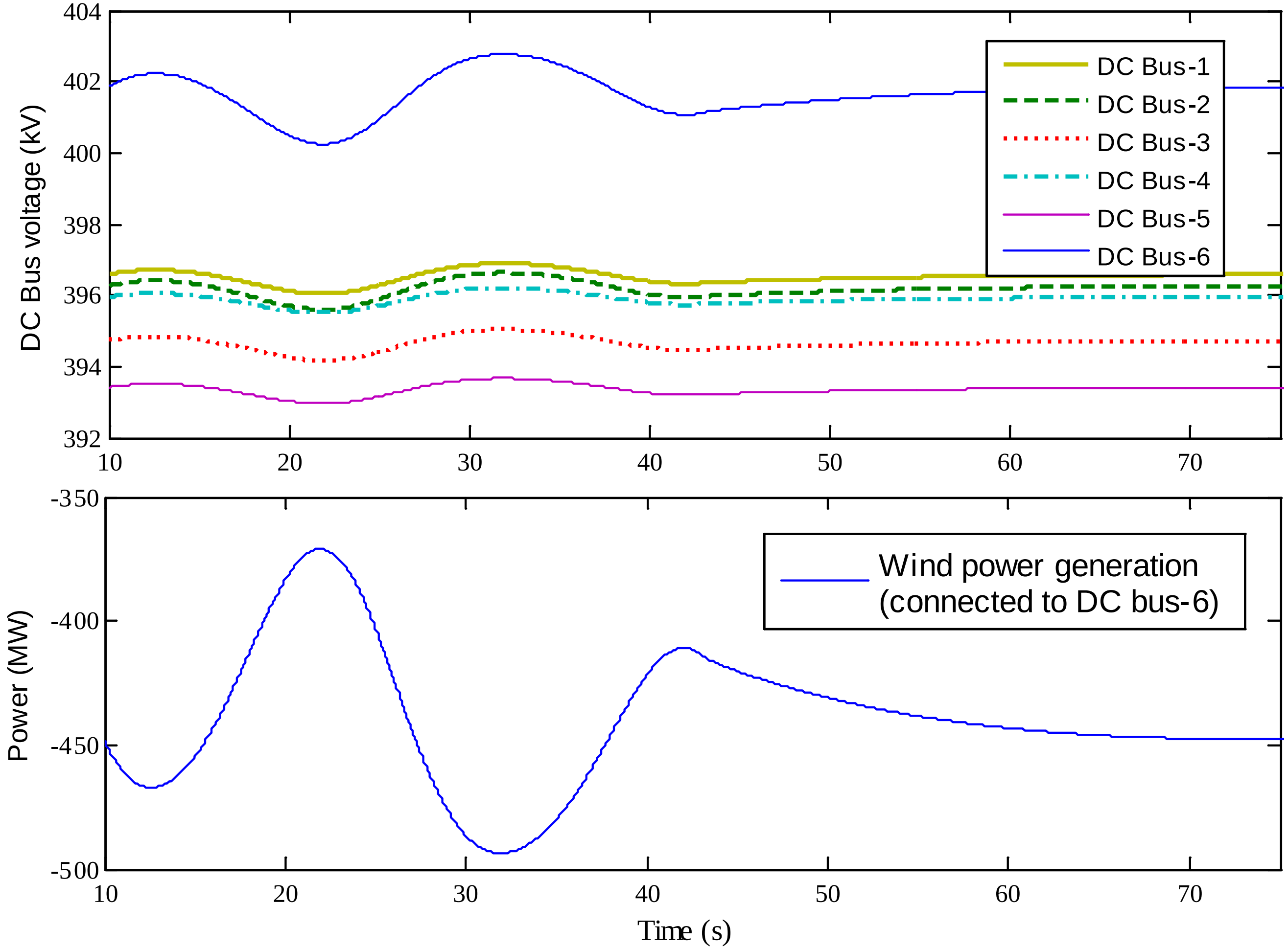
Contingency analysis

- Response to normal wind power variations
- Outage of DC line in the offshore grid
- Outage of offshore wind farm
- Outage in one of the ac grids

Simulation studies with 6-terminal DC grid system

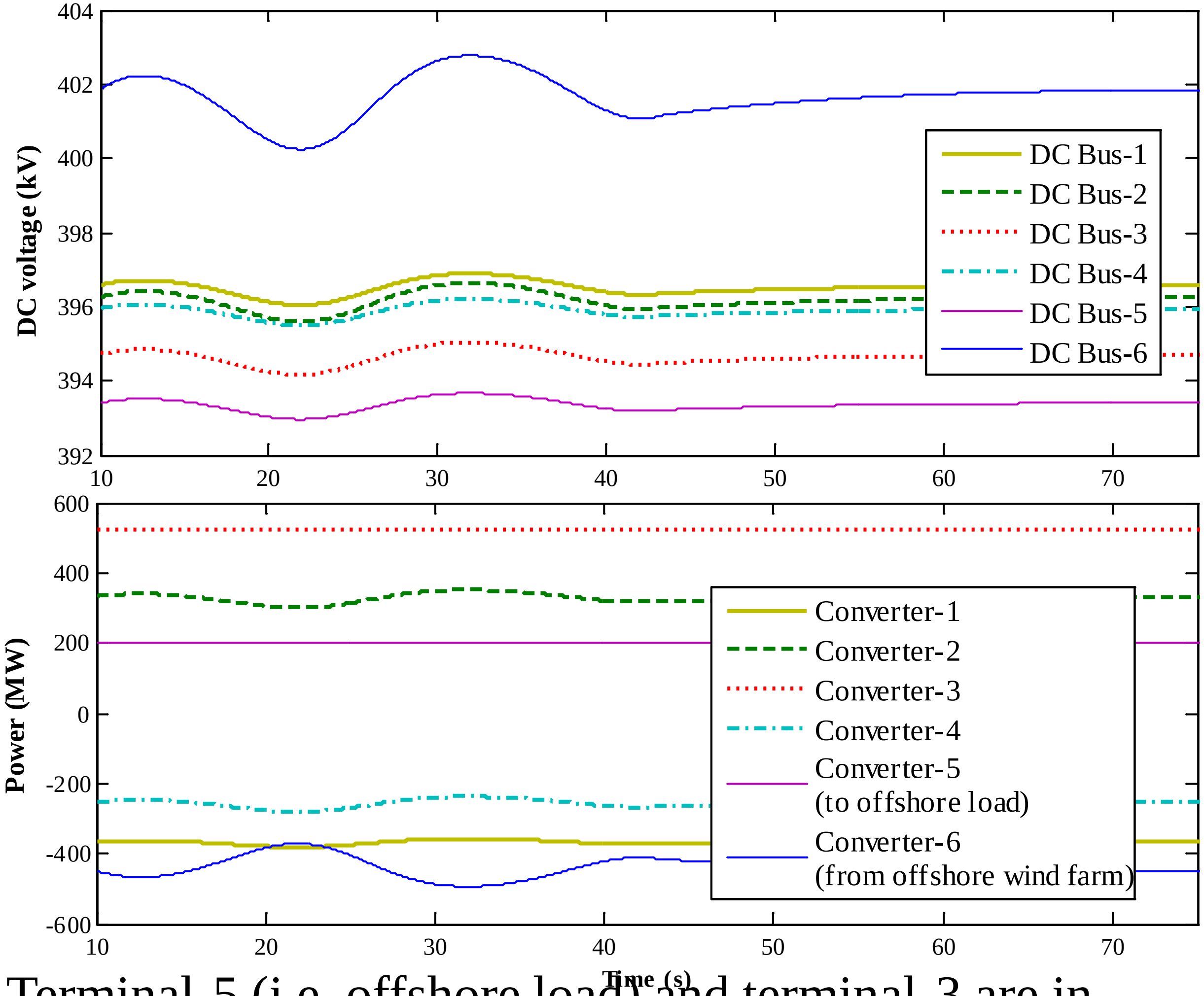


Variations of DC voltage with fluctuating wind power



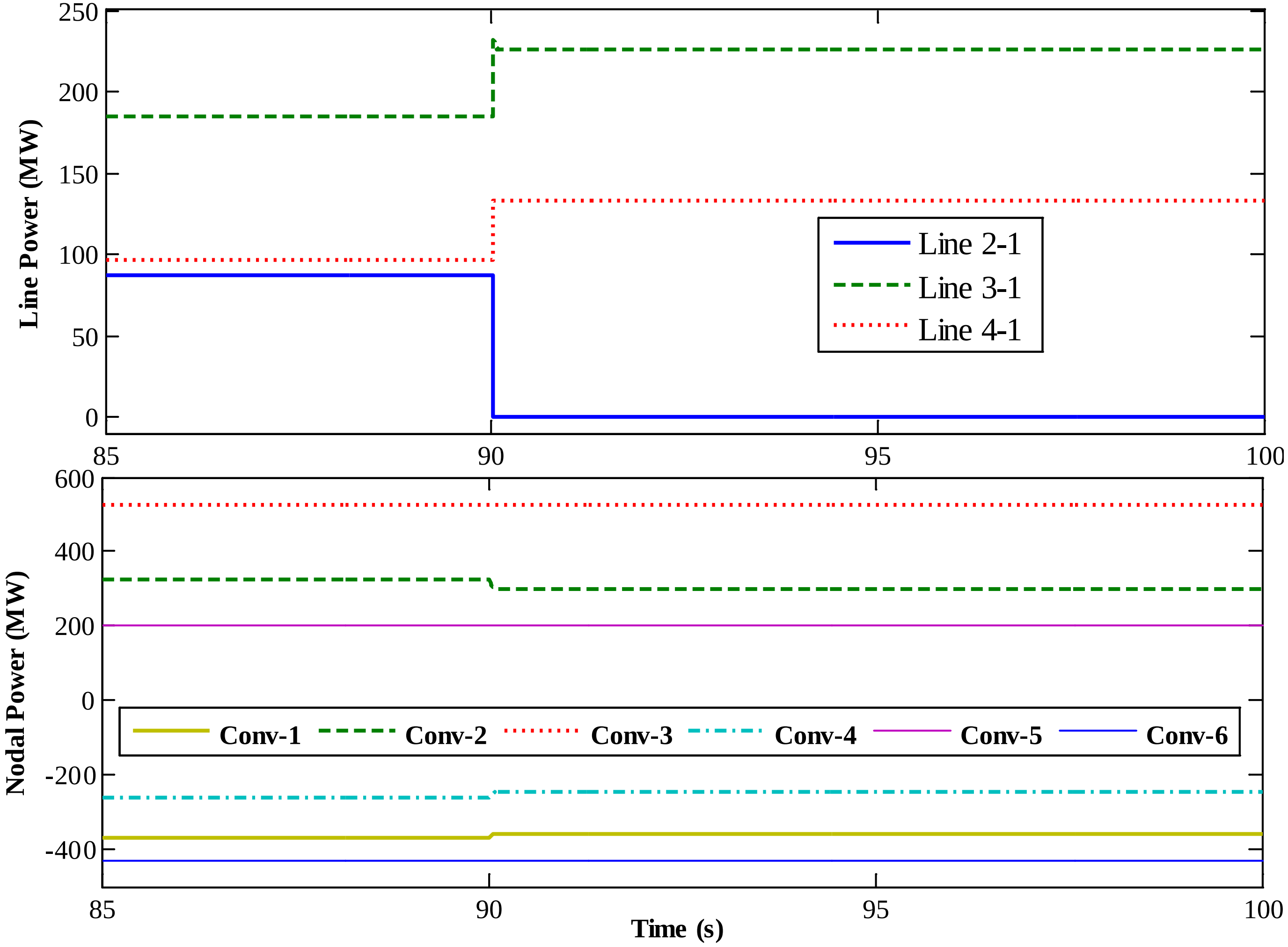
Voltage change is largest at the DC bus where power flow change first occurs

Use of DC voltage droop control for balancing power variations from the wind farm



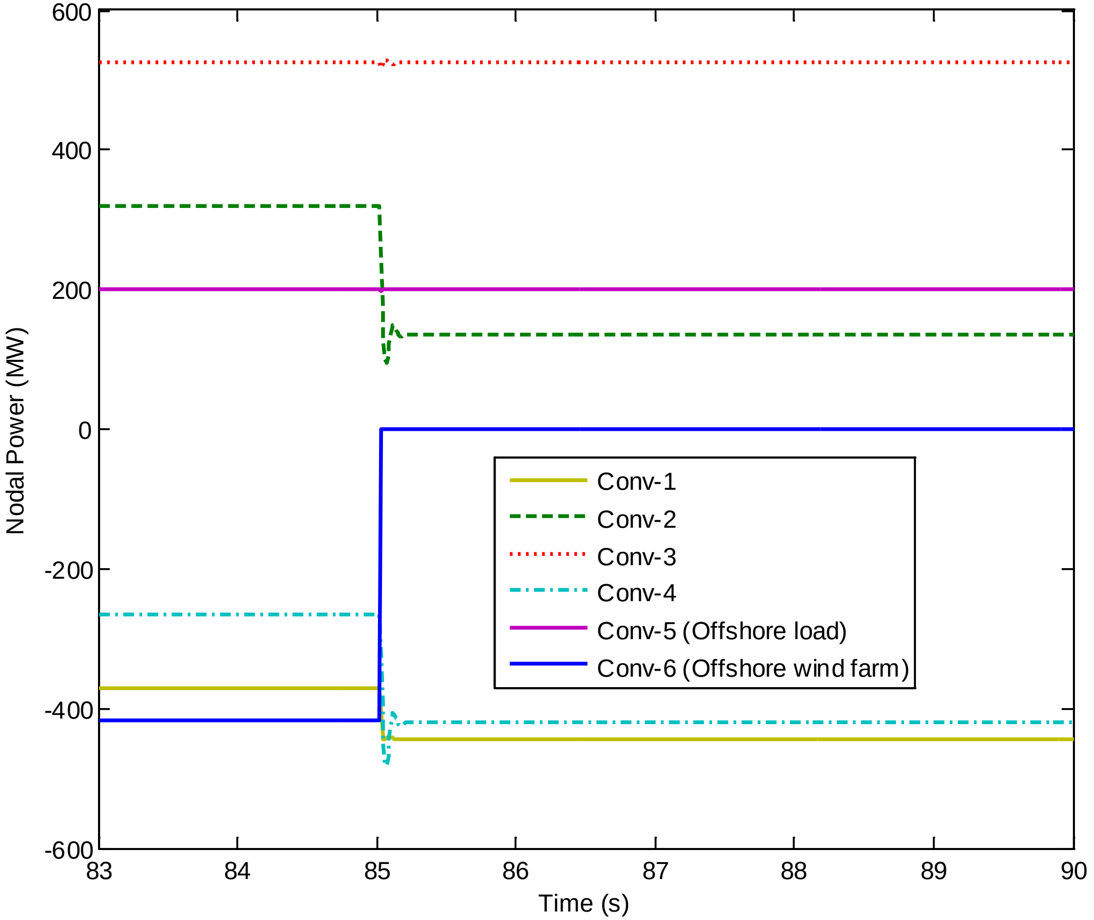
Terminal-5 (i.e. offshore load) and terminal-3 are in constant power mode. Terminals 1,2 and 4 are in DC voltage droop control mode.

Outage of DC line 1-2



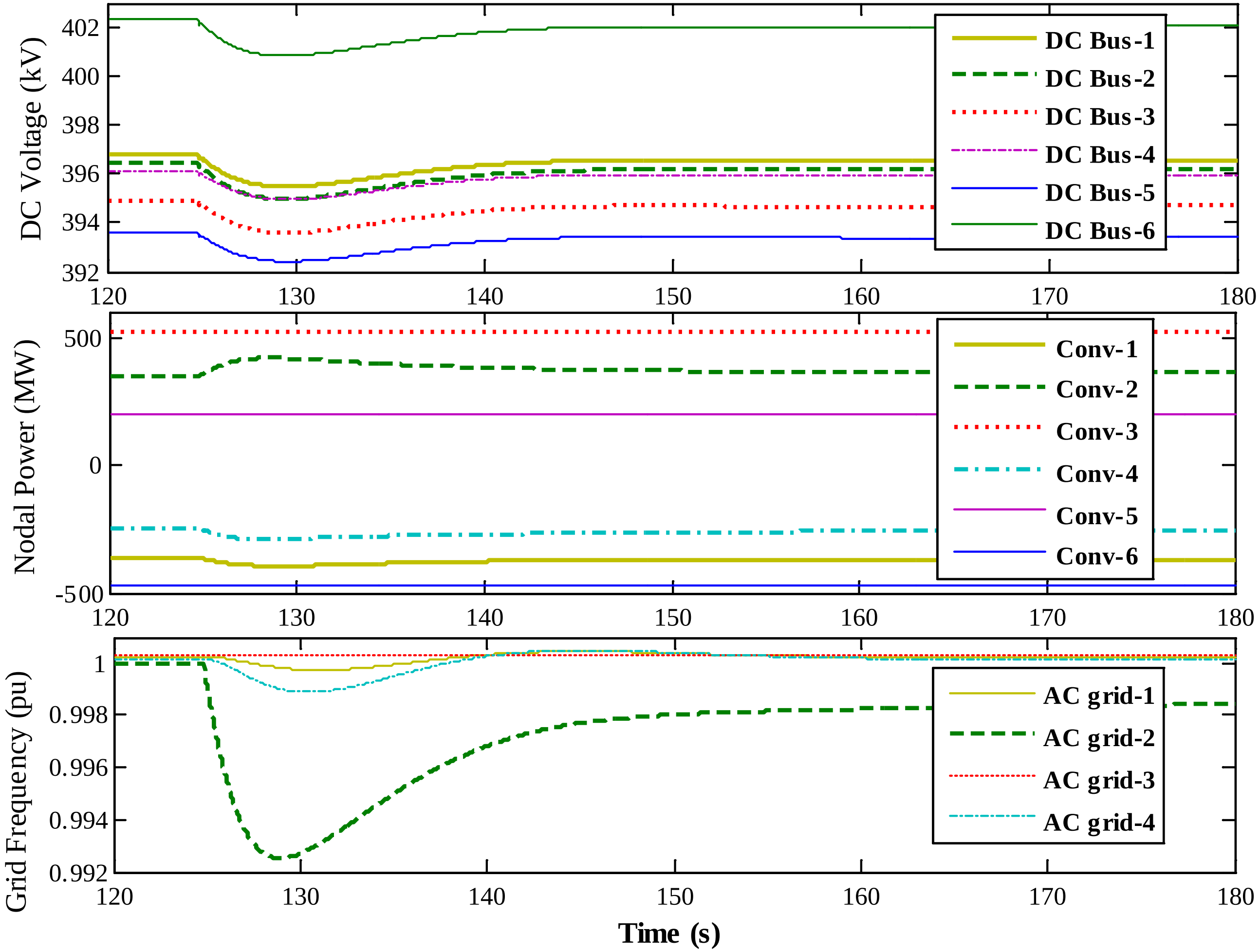
Terminal-1 continues to draw power via lines 1-3 and 1-4 when line 1-2 is disconnected. Small deviations in power flow occur due to unequal DC voltage changes observed by DC droop controllers at terminal 1, 2 and 4.

Outage of connection to windfarm



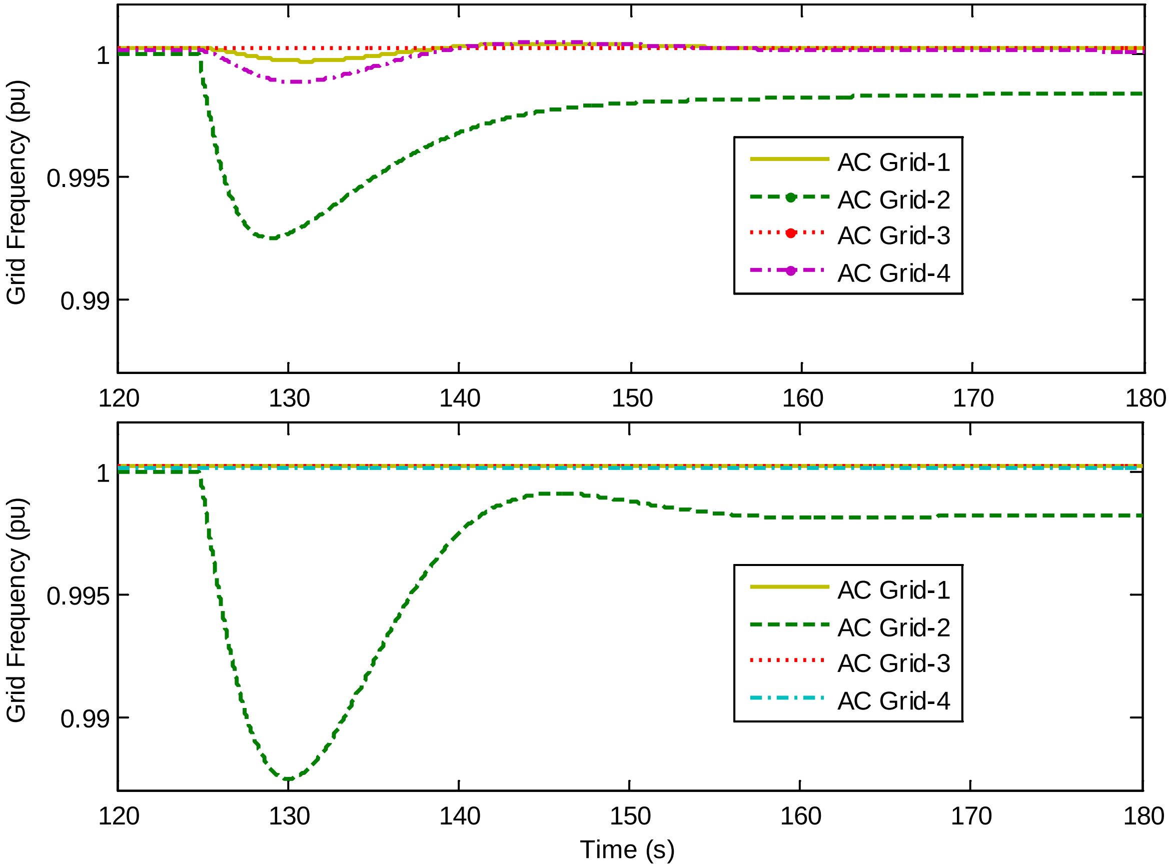
Terminals 1, 2 and 4 compensate for lost power flow from offshore wind farm.

Grid frequency support by meshed DC grid (Outage of 10% of generation in AC grid-2)



DC bus voltages show similar changes as AC grid frequencies.
Artificial frequency coupling between asynchronous AC grids.

Comparison of grid responses: with and without frequency support from DC grid



Frequency response improves with frequency control support from DC grid.

Concluding remarks

- MTDC has the potential to fully integrate power markets between asynchronous areas.
- Can be operated in a similar manner as ac grids.
- With the dc voltage droop control, no need of fast communication between converter terminals.
- Primary reserves can be traded between asynchronous areas (with frequency droop on the converter)

➢ ***Sufficient reserves, fast control and protection are key to ensure security of supply!***