multiDC: Controlling the power flows

Spyros Chatzivasileiadis
Associate Professor
DTU Center of Electric Power and Energy

Energinet Teknik Videnscafé, 8\textsuperscript{th} March 2019
multiDC

Innovative Methods for Optimal Operation of Multiple HVDC Connections and Grids

• Innovation Fund Denmark Grand Solutions

• Partners:
  – Two neighboring TSOs: Energinet, Svenska kraftnät
  – Three universities: DTU, KTH, Univ. of Liege
  – One major manufacturer: ABB
  – Advisory Board: RTE, Nordic RSC

• 25.7 million DKK
• 4 years; Start May 1, 2017
Three main drivers

• 100% renewables
  – Varying/zero inertia systems
  – North Sea Wind Power Hub

• 100% inverter-connected devices
  – How is stability and operation affected?
  – How to model them?

• HVDC Grids
Kriegers Flak

- Denmark – Germany: AC+HVDC
- First interconnection in the world that integrates off-shore wind farms along its path
- 400 MW Back-to-Back HVDC
- Wind Farm Kriegers Flak (DK) : 600 MW
- Wind Farm Baltic (DE) : 336 MW
- HVDC Master Controller to:
  - Control voltage
  - Avoid overloading
  - Ensure market outcome by mitigating wind forecast errors
North Sea Wind Power Hub

• Construction of island(s) in the middle of the North Sea

• Integration of up to 150 GW of off-shore wind farms

• HVDC interconnections to Denmark, Germany, the Netherlands, UK, Great Britain, Norway, Belgium

• Coupling the energy markets

• Agreement between Denmark, Germany, and the Netherlands already signed (2017)
How will the wind farms be connected to the island?

How will the island be connected to the mainland?

These are still open questions
AC: Low-frequency AC
HVDC: Point-to-point HVDC

AC Ring on the island

AC
AC
AC

UK
Netherlands
Germany
Denmark
Norway
Challenges and Opportunities

• Zero-inertia AC Ring
  – Fast transients

• Coordination of the control of the VSC converters
  – Grid-forming shared among the converters?
  – Dealing with failures (N-1)

• Sharing wind power among the countries
  – Ownership of wind farms
  – Do we need to adapt the market structures?
multiDC:
Addressing current challenges while preparing for the North Sea Wind Power Hub
The three pillars of multiDC

- Stability of zero-inertia systems
- Coordinated control of multi-area AC/DC systems
- Market integration of meshed HVDC connections
Stability of zero-inertia systems: multiDC contributions (May 2017-current)

- Robust frequency control for varying inertia systems
- Open-source VSC-HVDC model and analysis
  - Grid supporting VSC to weak AC grid
- Zero-inertia systems:
  - Investigate operation at frequencies different from 50 Hz
  - Identify gains that affect stability and propose alternatives

Misyris, Chatzivasileiadis, Weckesser, Robust Frequency Control for Varying Inertia Power Systems, ISGT Europe 2018, link to paper

Misyris, Guyennet, Chatzivasileiadis, Weckesser, Grid Supporting VSCs in Power Systems with Varying Inertia and Short-Circuit Capacity, accepted at IEEE Powertech 2019
System Configuration – Zero Inertia

- Offshore AC network
  - Wind generation Voltage Source Converters
  - Offshore Voltage Source Converters
- Onshore Voltage Converters
- Steady-state and small-signal stability analysis
Stable and unstable operating region

• The stable operating region increases when the offshore system operates at lower frequency
Impact of cables length on the small-signal stability limit – $f_n = 50$ Hz

Given the same control settings

- **Increase of cable length decrease** the small signal **stability limit** of the system

- Additional **filters** are required to **improve** the minimum **damping ratio** of the system

**Preliminary results!**
Impact of cables length on the small-signal stability limit – $f_n = 16.67$ Hz

Given the same control settings

- Increase of cable length **slightly reduces** the small signal stability limit of the system
- **Longer distances** between the wind farms **can be achieved**
- **Cost reduction**

Preliminary results!
Key insights (up to this point)

• **Minimum damping ratio** almost the same over the stable operating region

• In case of **lower frequency** on the offshore island
  • **Increase of stable operating space**
  • Increased robustness against wind generation power disturbances

• Further analysis necessary
Coordinated Control of multi-area AC/DC systems
Coordinated control of multi-area AC/DC systems

• Focus on Emergency Power Control (EPC) mechanisms and sharing of reserves between asynchronous systems

• Currently, EPC in Nordics works as follows:
  – If $f < \text{threshold}$ then transfer $= xx \text{ MW}$

• Goal: move from stepwise-triggers to droop-frequency control
  – Transmitted power is continuous and linearly dependent on the frequency deviation
EPC: Trigger (existing) vs Droop (proposed)

• Trigger: power continues to get transferred even if ROCOF becomes positive
  – This power does not help reduce the frequency nadir

• Droop: for any inertia level, the required power is less than in the “trigger” EPC

<table>
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</table>

- Does not cross the minimum freq. threshold
- Uses 61% less power

Obradovic, Ghandhari, Eriksson, *Assessment and Design of Frequency Containment Reserves with HVDC interconnections*, Best Paper Award at NAPS 2018, [link to paper](#)
Cost savings from droop-frequency EPC

- Re-dispatch using synchronous generators (Synchronous re-dispatch)
- Re-dispatch using cross-border interconnections (Asynchronous re-dispatch)
- Frequency reserves support with fast Emergency Power Control (EPC) from HVDC links

Figure: Synchronous (left) and asynchronous (right) re-dispatch schematic map.
Cost Savings

• 2018:
  – Current paradigm (real data):
    Cost of 1.85 million Euros/year
  – Asynchronous redispatch:
    Savings of 0.2 million Euros/year
  – FCR with HVDC EPC:
    Savings of 0.9-1.8 million Euros/year

FCR with HVDC EPC:
• 2020: Savings of 1.9 – 2 million Euros/year

• 2025: Savings of 3 – 14 million Euros/year (50% cost reduction)
Next Steps

• **Stability assessment** of the *droop-frequency* control function of the HVDC EPC for the Nordic system
Market Integration of HVDC:
The cost of losses and the value of HVDC flexibility
Motivation

- **HVDC interconnectors:**
  - usually longer than AC interconnectors
  - often connecting areas belonging to different TSOs (at least in Europe)

- HVDC losses are not negligible

- If **price difference** between areas is **small**, TSOs cannot recover the cost of HVDC losses, i.e. cost of losses higher than potential revenue

- **Problem especially for transit countries,** such as Denmark
Some examples - Denmark

- In 2017 the **price difference** between SE3 and DK1 has been zero for more than 5300 hours (61%), resulting in **1.2 M€** losses.

- In 2017 the **price difference** between DK1 and DK2 has been zero for more than 6400 hours (73%), resulting in **0.8 M€** losses.

- In 2017 the **price difference** between DK1 and NO2 has been zero for more than 4000 hours (47%), resulting in **3.2 M€** losses.

Source: [https://www.nordpoolgroup.com/](https://www.nordpoolgroup.com/)
In 2017 the price difference between FI and EE has been zero for more than 6600 hours (76%), resulting in 3 M€ losses.

For these 5 HVDC interconnectors, losses amounts to 12 M€ per year.

Considering the number of HVDC interconnectors and all the new projects, this number is intended to grow significantly.

Source: https://www.nordpoolgroup.com/
Problem statement

- Introduction of an HVDC loss factor in market clearing*

*Fingrid, Energinet, Statnett, Svenska krafträttskonferensen, Analyses on the effects of implementing implicit grid losses in the Nordic CCR, April 2018

- To move from the explicit to the implicit method, a loss factor has to be included in the market clearing algorithm.

- Is it a good idea to introduce a loss factor only for HVDC lines in meshed grids?
Implicit grid losses - Nordic CCR

- Nordic TSOs, April 2018: *Analyses on the effects of implementing implicit grid losses in the Nordic CCR*
  - All simulations with implicit grid losses show an economic benefit
  - One exception is FennoSkan

* Fingrid, Energinet, Statnett, Svenska Kraftnät, *Analyses on the effects of implementing implicit grid losses in the Nordic CCR*, April 2018
Introduced Methodology for AC loss factors

More info:
A. Tosatto, T. Weckesser, S. Chatzivasileiadis, Market Integration of HVDC lines, available:
https://arxiv.org/abs/1812.00734
Economic evaluation

- The results show that the introduction of HVDC loss factors for this specific system is **beneficial** for most of the time.

- However, there are cases where the social welfare is **decreased** (>14%).

- **Theory guarantees** that this does not happen with LFs for **both AC and DC systems**

- The introduction of **AC-LFs double the benefit**.

More info:
Wrap-up and next steps

- **Is it a good idea to introduce a loss factor only for HVDC lines in meshed grids?**

- The HVDC loss factor can act positively or negatively w.r.t. the amount of system losses depending on the **system under investigation**.

- If to be introduced in the market clearing algorithm, the recommendation is to consider the losses in **both AC and DC systems**.

- **Next steps:** determine the value of HVDC corrective control, and price it appropriately.
Open-source models and demonstration
Development of a dynamic AC/HVDC Nordic model

- Open-source HVDC models for both LCC and VSC controllers
- Modeling both in RMS and EMT
- Powerfactory and RAMSES (U.Liege)
• 423 buses
• 80 synchronous machines
• 2 asynchronous areas
• Open source (including HVDC models)
multiDC contributions and next steps

• Develop **open source dynamic models** of both VSC-HVDC and LCC-HVDC

• Investigate stability of **zero-inertia** AC systems: robust control, operating at different AC frequencies

• Deep investigation of **droop-frequency based EPC** for HVDC
  – Stability analysis
  – Cost Savings

• **Market Integration of meshed HVDC lines**
  – Cost of losses
  – What is the value of HVDC flexibility? How to price HVDC corrective control?

**Demonstration at PowerlabDK**

– **Advanced functionalities of Kriegers Flak Master controller**

– Zero-inertia systems: Impact of **RMS vs EMTP** modelling

– **Droop-frequency-based EPC** for the Nordic system

Hopefully test the most promising functions at Energinet!
Conclusions

• **multiDC: Holistic approach** to the emerging problems of multiple HVDC interconnections and grids
  – Zero-inertia AC grids
  – Emergency power control coordination of multi-area AC/DC grids
  – Market Integration of HVDC

• Developing solutions applicable to the North Sea Wind Power Hub

• Real implementation at PowerlabDK
Interested to hear more?
Join us in the multiDC demonstration event at DTU in September 2019!

www.multi-dc.eu