EnergyVille

HVDC as an enabling technology for energy transmission and service provision

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Outline

1. Introduction
2. Ancillary services from HVDC
3. Case studies
4. Conclusion

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Towards a hybrid AC/DC power system

Ambitious climate targets

- Offshore wind: 300 → 450 GW by 2050
  - ± 35 GW of wind offshore installed to date (2/3 in Europe)
  - ± 100 GW by 2030
  - North Sea: 200 GW by 2050
- Solar and onshore wind: similar developments
- Grid: Meshed HVDC grids are the only realistic option:
  - Connections are increasingly further from shore
  - To be integrated in the existing system (hybrid AC/DC)
  - Towards new backbone grid
- Budget: Offshore requires massive investments (EC: 2/3rd of 800 Billion by 2050)

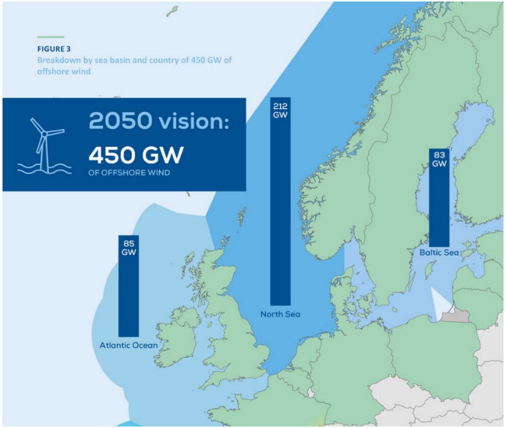

Figure source: Our energy, our future, How offshore wind will help Europe go carbon-neutral, Wind Europe, November 2019

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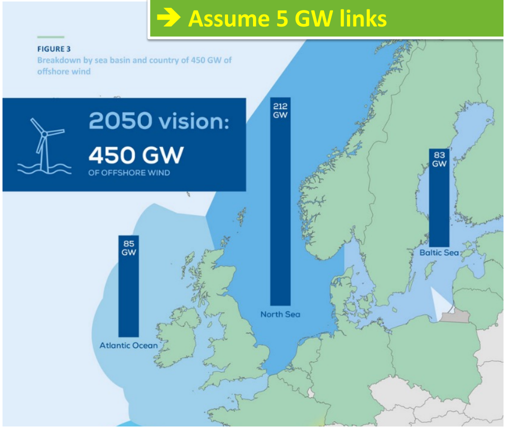
➔ Assume 5 GW links



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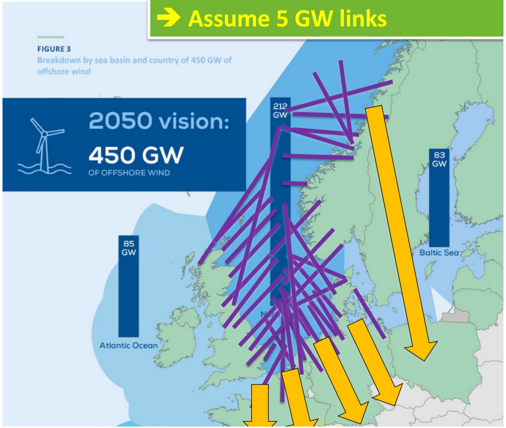

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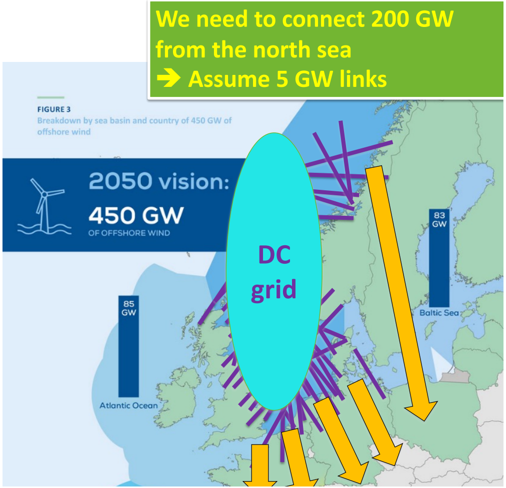

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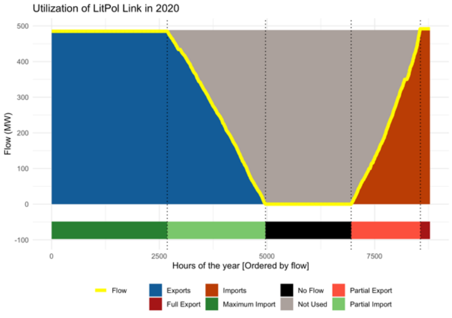
HVDC is an integral part of the European energy market

- Energy trade between different market participants
  - Power flow on HVDC lines is from low price zones to high price zones
  - Fully controllable injections
  - Not fully used
- Ancillary services trade between different market participants



Utilization of LitPol HVDC link in 2020[1].

[1] T. Borbáth, et al., Statistical analysis of COVID effect on HVDC flows in Europe, IEEE PES GM (2021)

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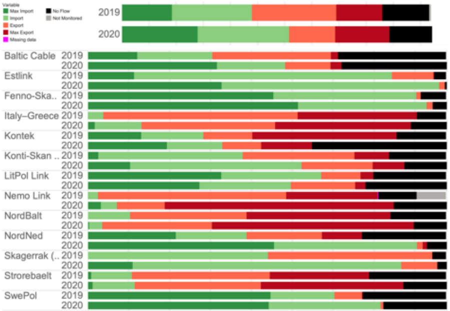

Usage of the interconnectors based on day-ahead schedules. Darker colors represent hours with saturated available capacities. Black color represents hours with no flows on the interconnector[1].

[1] T. Borbáth, et al., Statistical analysis of COVID effect on HVDC flows in Europe, IEEE PES GM (2021)

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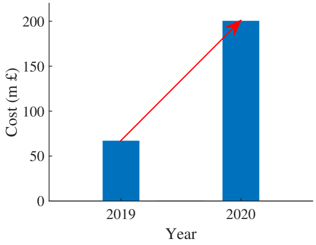

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[2] L. Badesa, et al., Ancillary services in Great Britain during the COVID-19 lockdown: A glimpse of the carbon-free future, Applied Energy, 285 (2021)

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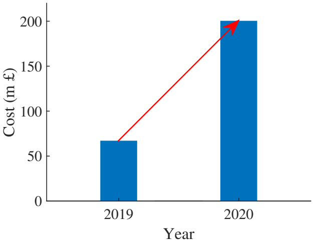
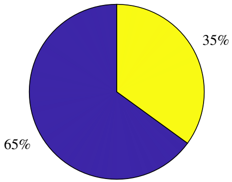
  - Not fully used
- Ancillary services trade between different market participants
- Ancillary services cost increased 3 times in covid times in Great Britain[2]
- Ancillary services expected to be 35% of system operation cost by 2050[2]
- Can we use HVDC to deliver/share/transmit ancillary services?





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HVDC to exchange ancillary services

- Large power transfer capabilities over longer distances
- Connecting different energy systems
  - Different generation portfolio
  - Different weather pattern
  - Wind farms and energy islands connected to various grids
  - Different rules/requirements in different control areas
- Fast response, even in the ms range ($\Rightarrow$ Inertia!)
- Robust control capability
- Active power control and reactive power control (with VSC HVDC)
- Can HVDC be used for exchange of ancillary services? YES

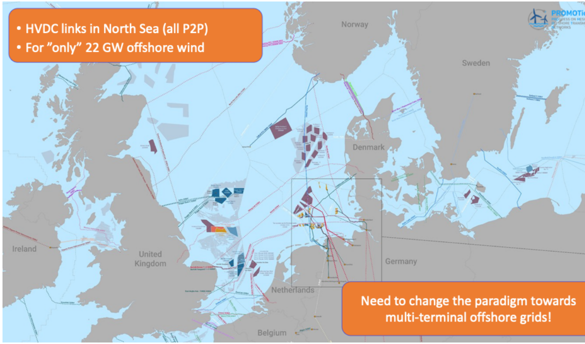

Figure source: PROMOTioN project, EU Set Plan IWG on HVDC

Outline

Ancillary services

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- **Ancillary services**: Grid support services required by system operator (SO) to guarantee system security.
- Ancillary services provide SOs with the following capabilities:

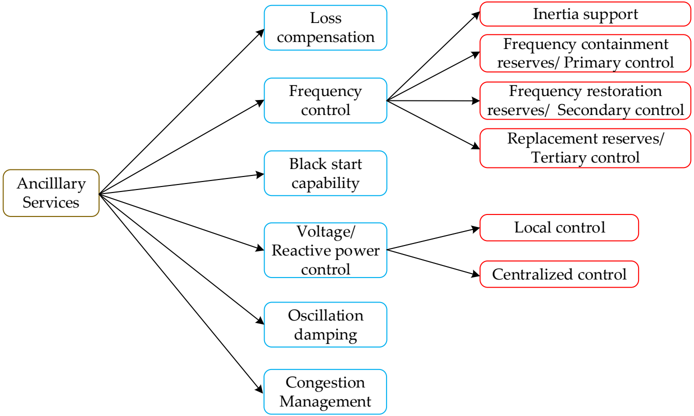

Figure source: A. Kaushal and D. Van Hertem, An Overview of Ancillary Services and HVDC Systems in European Context, Energies 2019, 12, 3481

Ancillary services with HVDC systems[1]

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System ⇒ / Service ⇓	Asynchronous		Synchronous		Offshore	
	LCC-based	VSC-based	LCC-based	VSC-based	LCC-based	VSC-based
Inertia	++	+++	NA	NA	++*	++*
FCR	+++	+++	NA	NA	++*	++*
FRR	+++	+++	NA	NA	++*	++*
RR	+++	+++	NA	NA	++*	++*
Voltage/Reactive power control	-	+++	-	+++	-	+++
Blackstart	-	++	-	++	-	++
Congestion management	+++	+++	+++	+++	-	-
Oscillation damping	++	+++	++	+++	+	+

The symbol -, +, ++ and +++ means that the HVDC systems cannot provide the service, can provide the service, can provide the service similar to conventional AC systems and can provide the service better than AC systems respectively
*-HVDC system requires appropriate controls at the offshore side

[1] A. Kaushal and D. Van Hertem, An Overview of Ancillary Services and HVDC Systems in European Context, Energies 2019, 12, 3481

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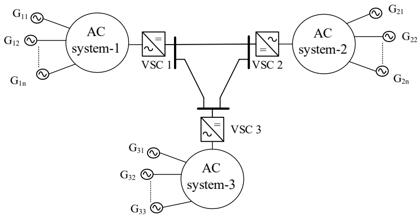
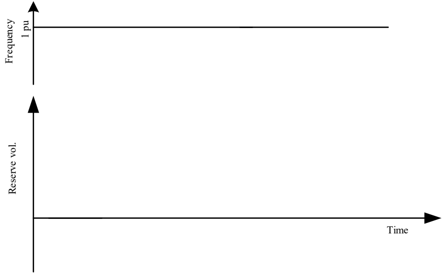
RR	+++	+++	NA	NA	++*	++*
Voltage/Reactive power control	-	+++	-	+++	-	+++
Blackstart	-	++	-	++	-	++
Congestion management	+++	+++	+++	+++	-	-
Oscillation damping	++	+++	++	+++	+	+

Ancillary services can be provided by HVDC systems in a manner similar to or better than AC systems

Frequency control

Set of control actions aimed at maintaining the system frequency at its nominal value





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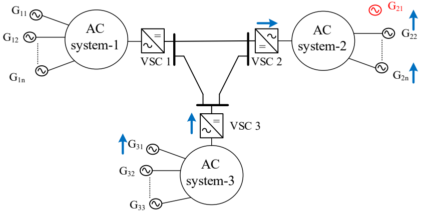

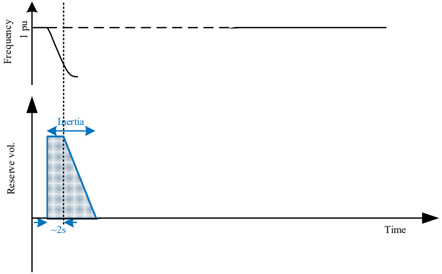

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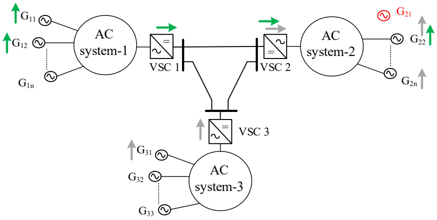

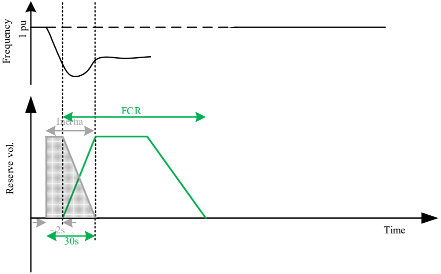

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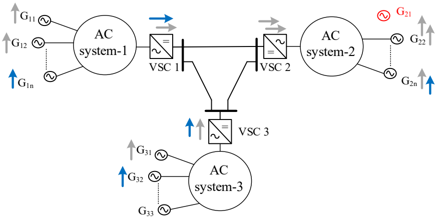
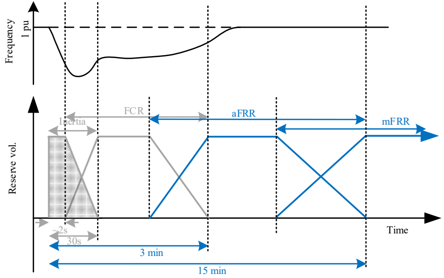
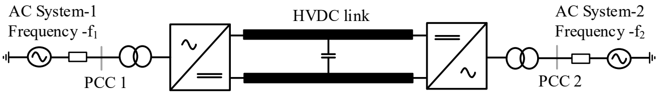




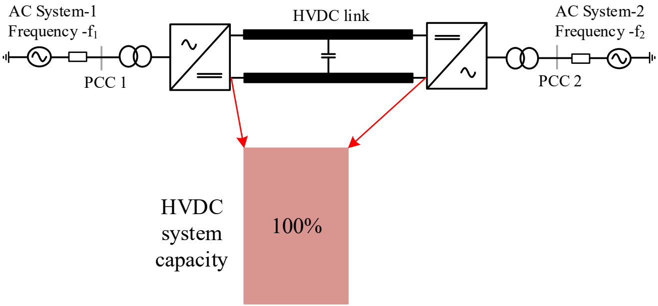
Reserve capacity procurement carried out in advance
Reserve activation timings based on [1], however these vary from TSO to TSO

[1] Statnett: System operations and market development plan 2017-2021

HVDC system use



Using HVDC to transmit energy and services



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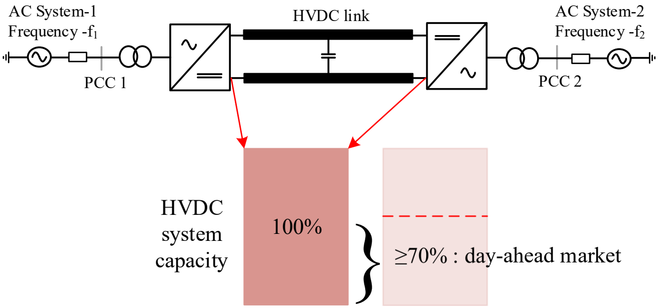

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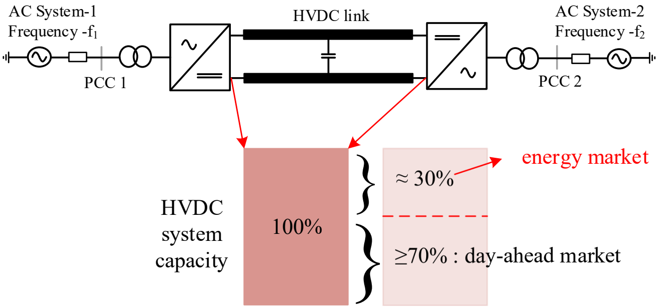

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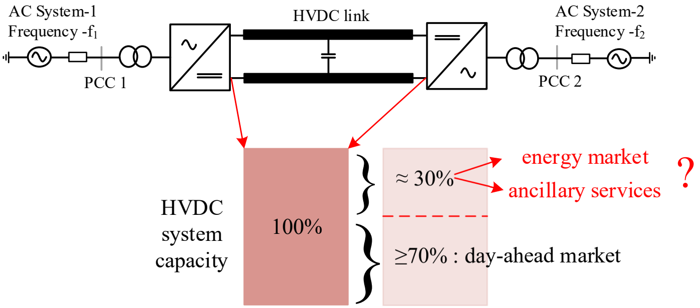

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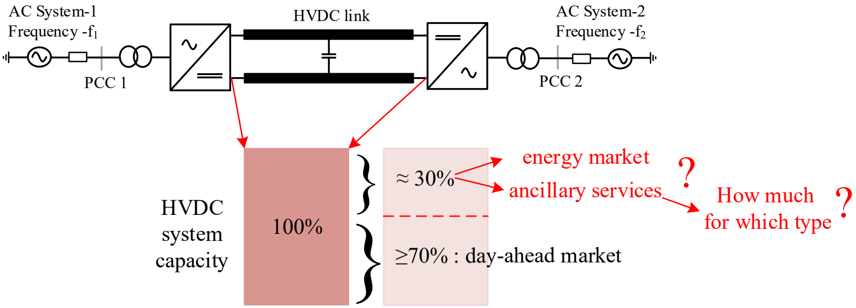

- Energy and different services might be transmitted over the same line, controlled
- Energy and services exchange might be in different directions
- What is the tradeoff between services and energy?
- What is the value of overrating/overloading the HVDC connection?

Outline

Frequency control reserves with HVDC

- Effect of frequency reserve procurement on the operational costs for TSO?
  - Optimal HVDC line capacity allocation for reserves?
  - Nordlink HVDC used for analysis
  - Using historical cost data from ENTSO-E transparency platform
  - 30% reserve volume can be procured from other TSOs

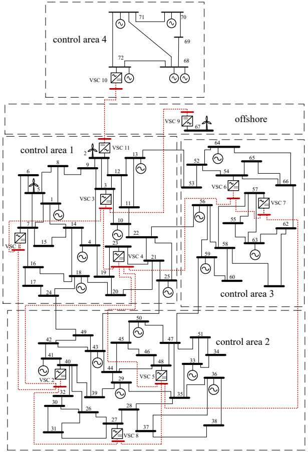

Figure source: A. Kaushal, et al., Frequency restoration reserves procurement with HVDC systems, The 17th International Conference on AC and DC Power Transmission (ACDC 2021), 2021, pp. 155-160

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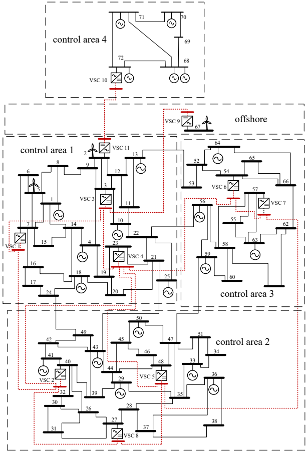

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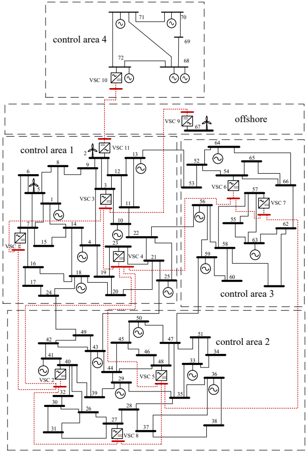

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Inertia support from HVDC

- Low inertia in Nordic synchronous area: hours with low load and large share of non-synchronous generation i.e. wind and HVDC (summer days)[1]
- Remedial actions (among others):
  - Conventional technologies
  - Virtual inertia from HVDC: emulation of synchronous machine dynamic
- What would be the impact of virtual inertia consideration on system operational cost?
- Assumptions:
  - Energy available on the other side of HVDC system and minimal effect on system frequency
  - Converter control already implemented
  - Test scenario and HVDC system parameters from [2] considered

[1] Nordic Analysis Group NAG, Requirement for minimum inertia in the Nordic power system, ENTSO-E, 2021
[2] S. D'Arco, et al., P-HiL Evaluation of Virtual Inertia Support to the Nordic Power System by an HVDC Terminal, 2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), 2020, pp. 176-180

Inertia support from HVDC: economical aspects

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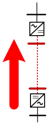
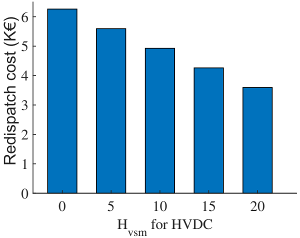


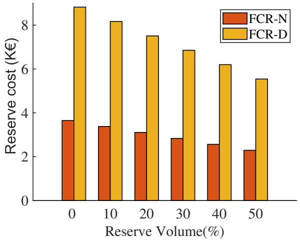


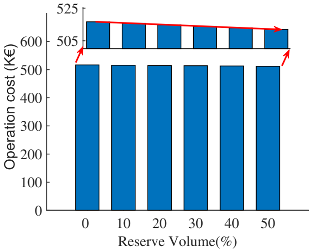
Date	Time (Hrs)	Power flow (MW)	Day-ahead price [€/MWh]	
			Germany	Norway
31-07-2021	0700	-1400	15	38

System kinetic energy	115 GWs
HVDC line loading	1400 MW
HVDC line overloading capability	10%
Alternate inertia source	Gas plant (H=4.2)

- Inertia support from HVDC constrained due to available capacity; overload capability of HVDC system utilized
- Increasing inertia constant for HVDC (H_{vsm}) from 0 (no virtual inertia support) to 20 reduces the redispatch cost by 42%

FCR procurement: case-1

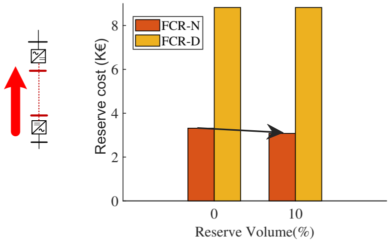




- FCR procurement from outside control area beneficial
- Use of HVDC reduces the reserve procurement cost by 37% w.r.t. local procurement cost
- Use of HVDC also reduces the system operation cost (dispatch cost + reserve) by 0.9% of initial dispatch cost for hourly system operation

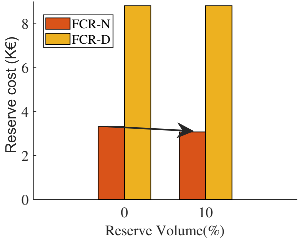
Date	Time (Hrs)	Power flow (MW)	Day-ahead price [€/MWh]		FCR price [€/MWh]	
			Germany	Norway	Germany	Norway
10-12-2021	2345	1404	221	135	4	14

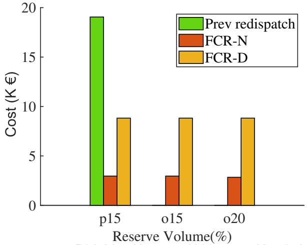
FCR procurement: case-2 (system operation at rated capacity)



- No capacity available; same FCR cost with and without HVDC
- Overloading HVDC system by 10% reduces FCR cost by 2%

FCR procurement: case-2 (system operation at rated capacity)

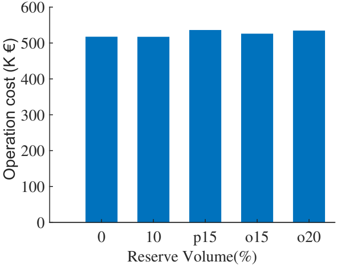




- No capacity available; same FCR cost with and without HVDC
- Overloading HVDC system by 10% reduces FCR cost by 2%
- Preventive redispatch increases reserve procurement cost (xlabel p15)
- Reserving HVDC capacity before day-ahead market clearing (xlabel o10, o20) ⇒ lower FCR reservation cost

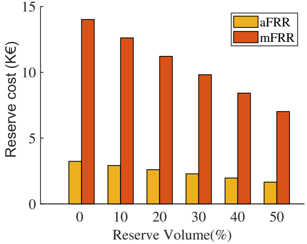
Date	Time (Hrs)	Power flow (MW)	Day-ahead price [€/MWh] Germany	Day-ahead price [€/MWh] Norway	FCR price [€/MWh] Germany	FCR price [€/MWh] Norway
26-12-2021	2230	-1440	98	164	4	13.7

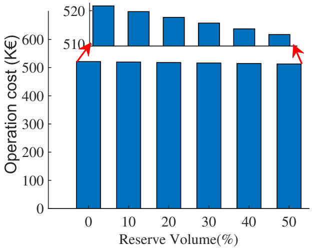
FCR procurement: case-2 (system operation at rated capacity)



- Utilizing HVDC system overloading capability reduces overall operation cost
- Preventive redispatch increases overall system operation cost (xlabel p15)
- Reserving HVDC capacity before day-ahead market clearing (xlabel o10, o20) increases system operation cost; lower than taking preventive action

FRR procurement: case-1

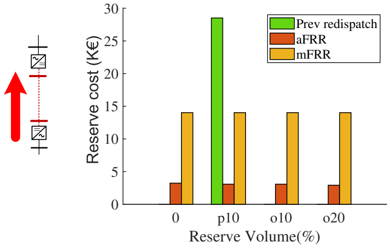




- Reserve procurement using HVDC system beneficial
- No limit imposed by HVDC system capacity
- Use of HVDC reduces the reserve procurement cost by 50% w.r.t. local procurement cost
- Use of HVDC also reduces the system operation cost (dispatch cost $+$ reserve) by 2% of initial dispatch cost for hourly system operation

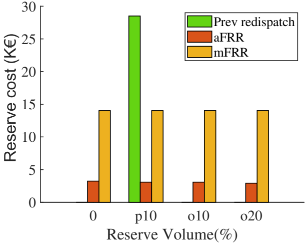
Date	Time (Hrs)	Power flow (MW)	Day-ahead price [€/MWh]		FRR price [€/MWh]	
			Germany	Norway	Germany	Norway
10-12-2021	2345	1404	221	135	0.02	10.62

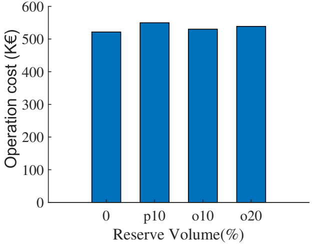
FRR procurement: case-2 (system operation at rated capacity)



- No capacity available, overloading capability not used
- Preventive redispatch increases reserve procurement cost (xlabel p10)

FRR procurement: case-2 (system operation at rated capacity)

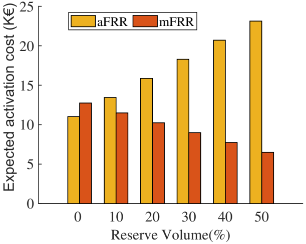




- No capacity available, overloading capability not used
- Preventive redispatch increases reserve procurement cost (xlabel p10)
- Preventive redispatch and capacity reservation before day-ahead market clearing (xlabel p10, o10, o20): increases system operation cost

Date	Time (Hrs)	Power flow (MW)	Day-ahead price [€/MWh] Germany	Day-ahead price [€/MWh] Norway	FRR price [€/MWh] Germany	FRR price [€/MWh] Norway
26-12-2021	2230	-1440	98	164	0.19	20.69

FRR procurement: case-1 (expected activation cost)



- Reserve activation cost different than reserve procurement cost
- Procurement of reserves from other TSO increases the expected activation cost by 25%
- Expected reserve activation cost would influence the decisions for limited system capacity

Outline

1. Introduction
2. Ancillary services from HVDC
3. Case studies
4. Conclusion

Conclusions

- Ancillary services, in particular reserve exchange over HVDC systems is beneficial
- Power flow direction on HVDC link influences the reserve sharing capabilities
  - Allocation of HVDC system capacity for reserves depends on the relative cost of energy and services
  - fixed capacity reservation will lead to suboptimal system operation $\Rightarrow$ dynamic capacity reservation
- Only generator capacity reservation is not true indicator of the reserve costs; expected reserve activation cost should also be considered
- While energy trade still dominates the economic return, ancillary services provision can impact the design of the HVDC system
- (Temporary) overload capability of converters can be cost-effective through AS provision
- System complexity significantly increases when stacking of multiple ancillary services across HVDC grids is considered

Energy Ville

HVDC Inertia Provisions

Thank you!

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