Unbalanced operation of HVDC grids

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June 20, 2022

BTech: Electrical Engineering
IIT Roorkee (2014)

System Operator at an HVDC s/s
Power Grid Corporation of India Ltd (2016)

MTech: Power Electronics and Power System

IIT Bombay (2018)

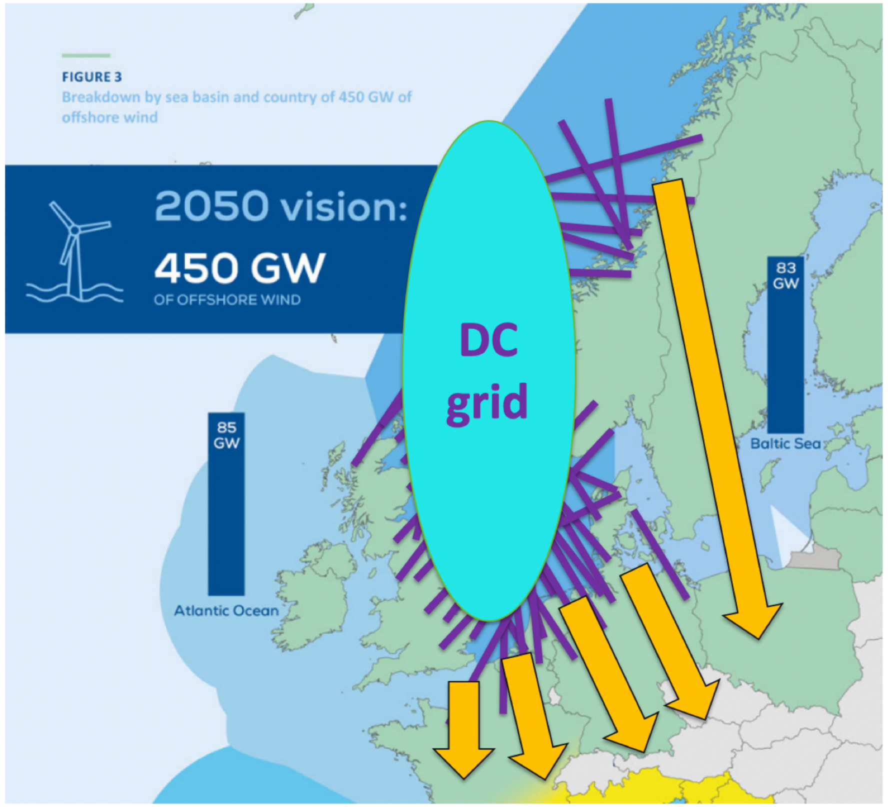
Research Assistant

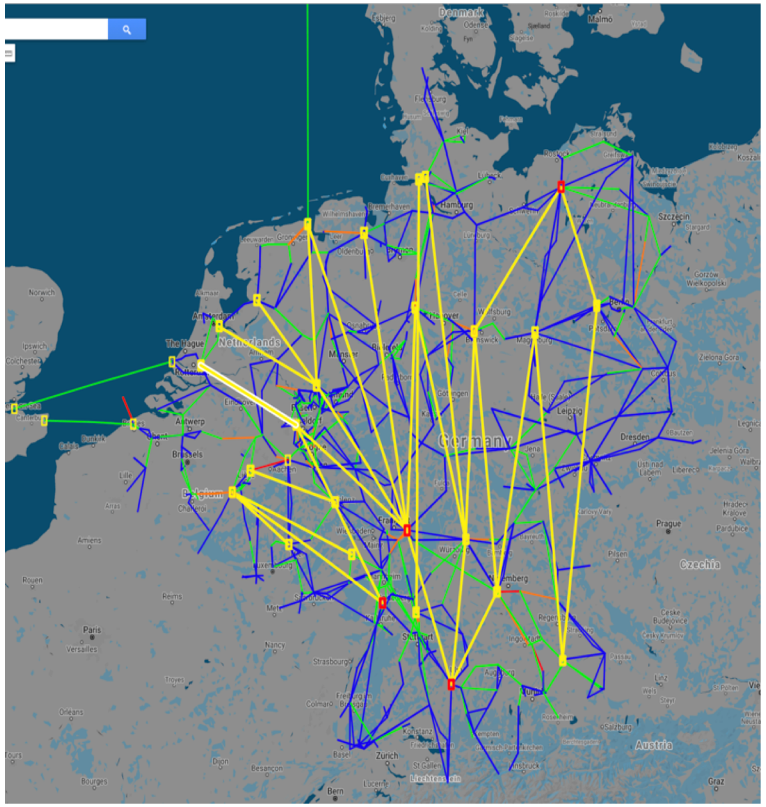
Michigan Tech (2019)

Doctoral Researcher: Electrical Engineering
KU Leuven (Sept 2019 onwards)

Motivation:

- 300-> 450 GW off offshore wind to be installed by 2050
- North Sea: 200 GW by 2050





We need to connect 200 GW from the north sea
➔ Assume 5 GW links

Robust and secure transmission network expansion planning with HVDC grids

- Long-term view ➔ 30-50 years
- Uncertainty ➔ generation, demand, investment, technology etc.
- High dimensionality ➔millions of constraints and variables, many of them binary

} Transmission Network Expansion Planning

- Overhead lines or under ground/ sub sea cables
- HVDC configurations:
  - Monopolar (symmetric/asymmetric), bipolar, metallic return or ground return etc.
- Additional resources to control the voltage and power flow in the network

} HVDC Grids

- A lot of uncertainties are involved: Deterministic approach not sufficient

} Robust and Secure

HVDC grid configurations

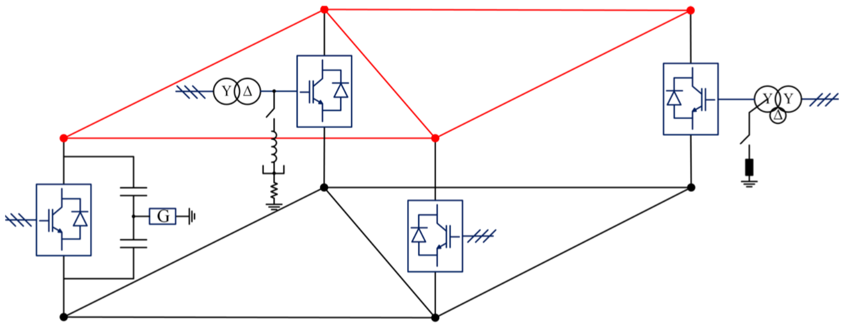


Fig: Symmetrical monopolar HVDC grid

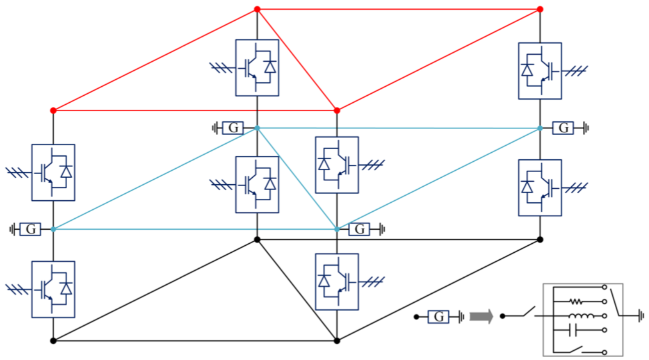


Fig: Bipolar HVDC grid

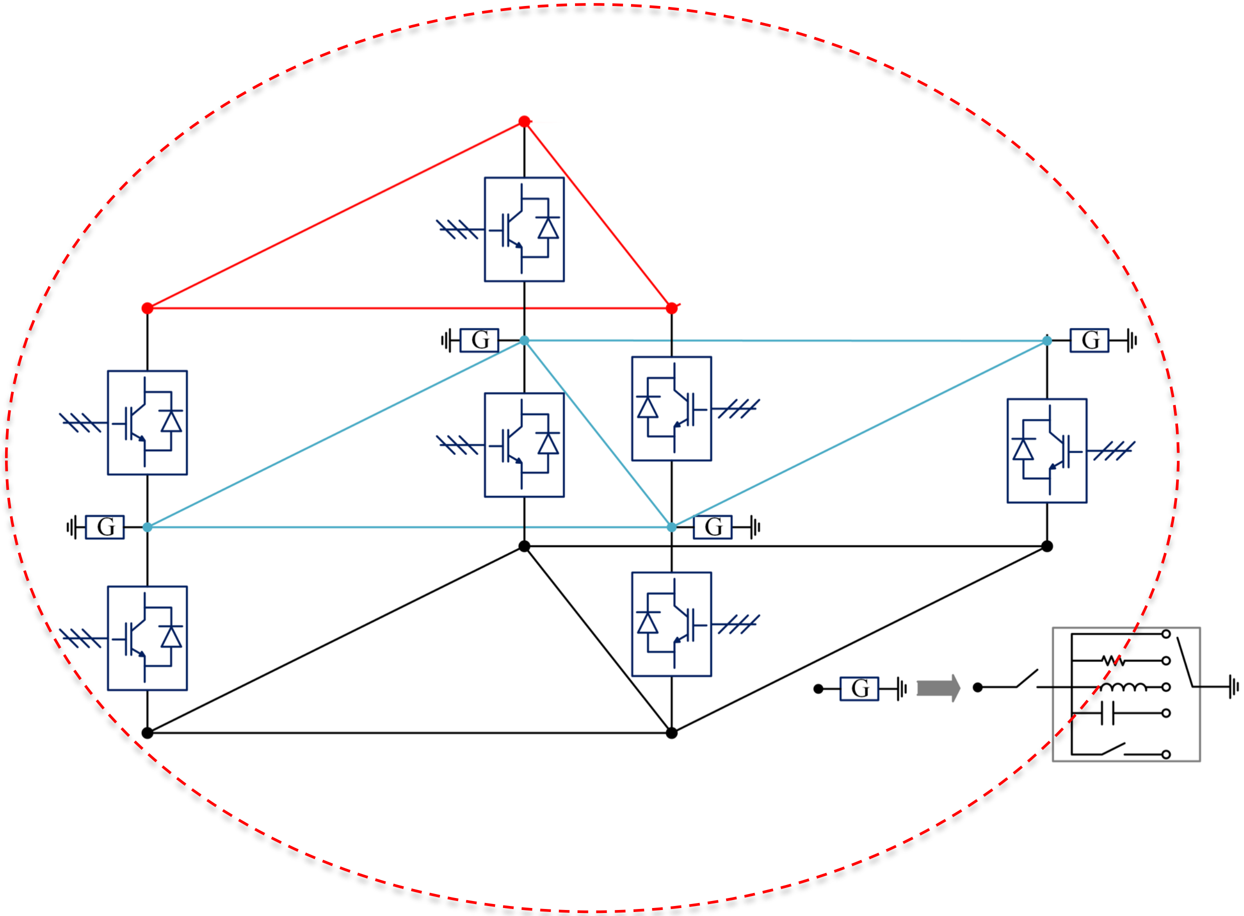


Fig: Mixed configurations

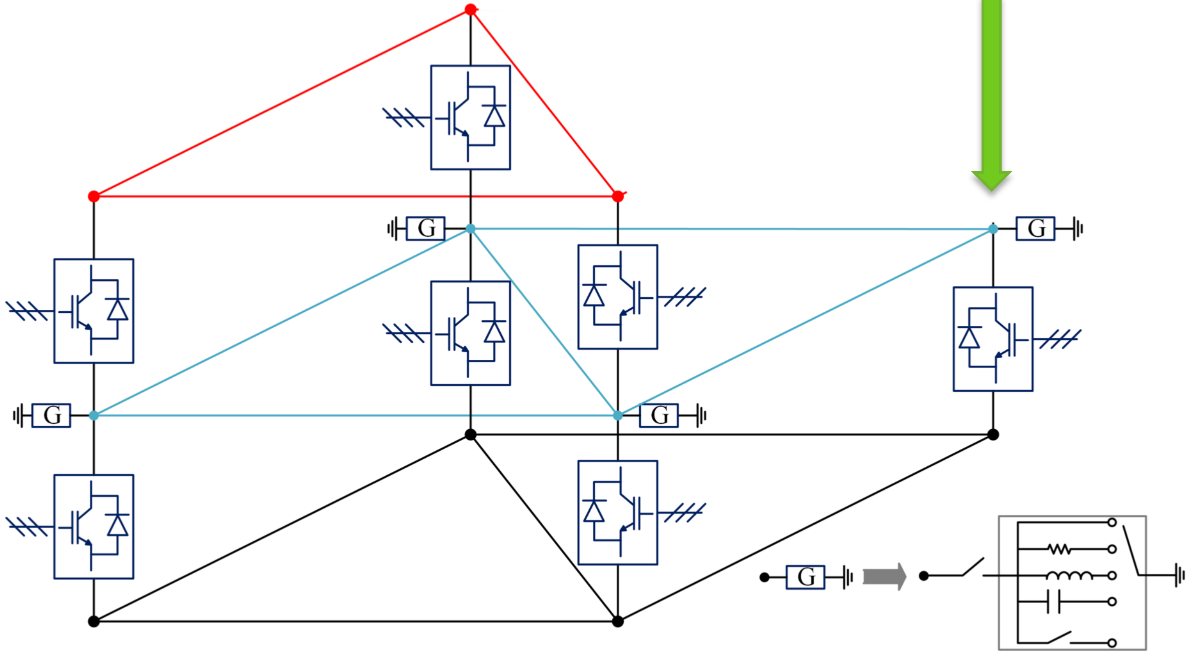
Unbalance in DC grids

- As of now DC side is always considered to be balanced (symmetric) ➔ *same in future?*

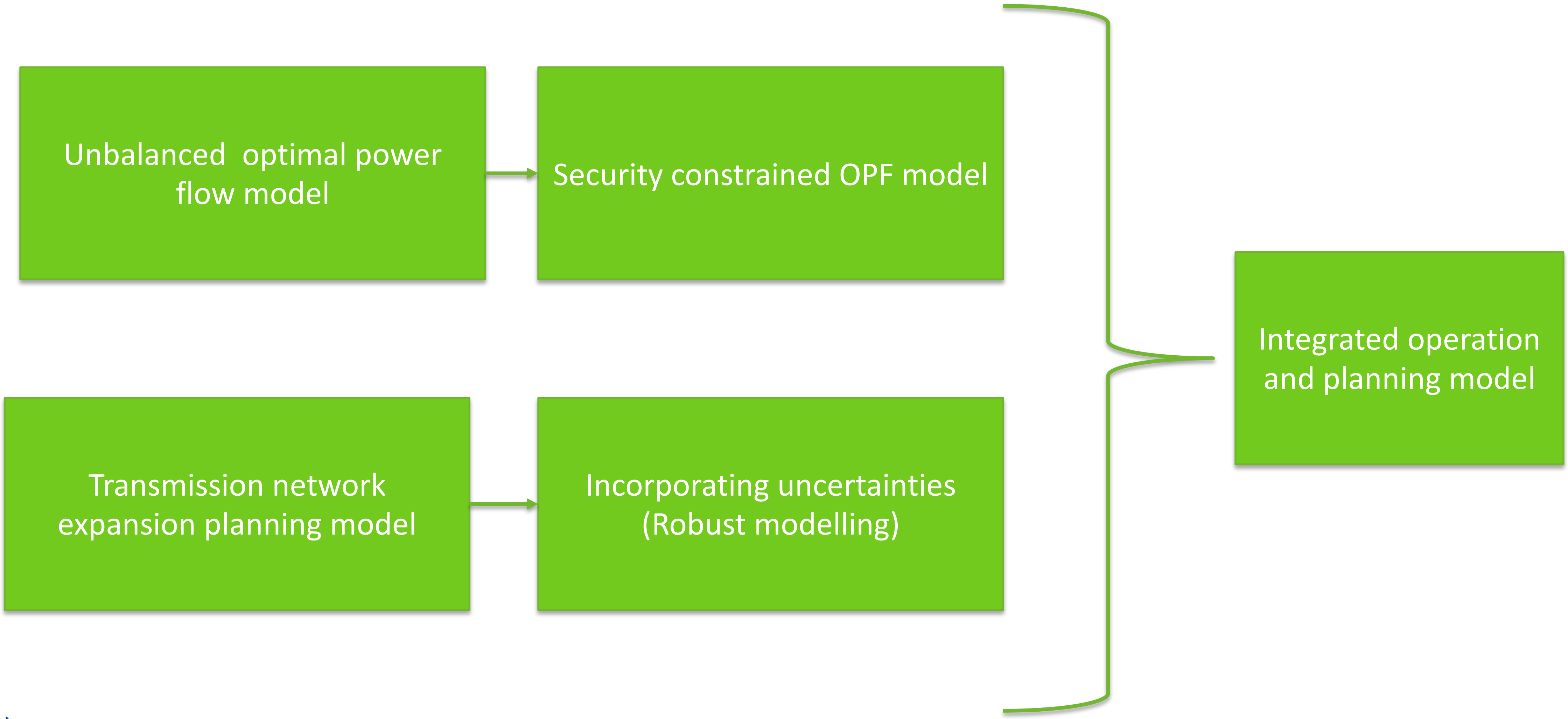
- Single pole outage?
- Monopolar tapping on a bipolar backbone: Offshore wind

- Operating mixed configurations causes unbalances in the DC grid

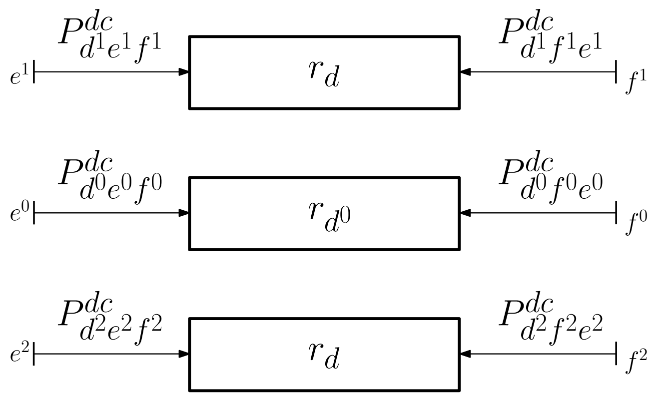
Is it beneficial to build and operate such a system?



Building blocks:

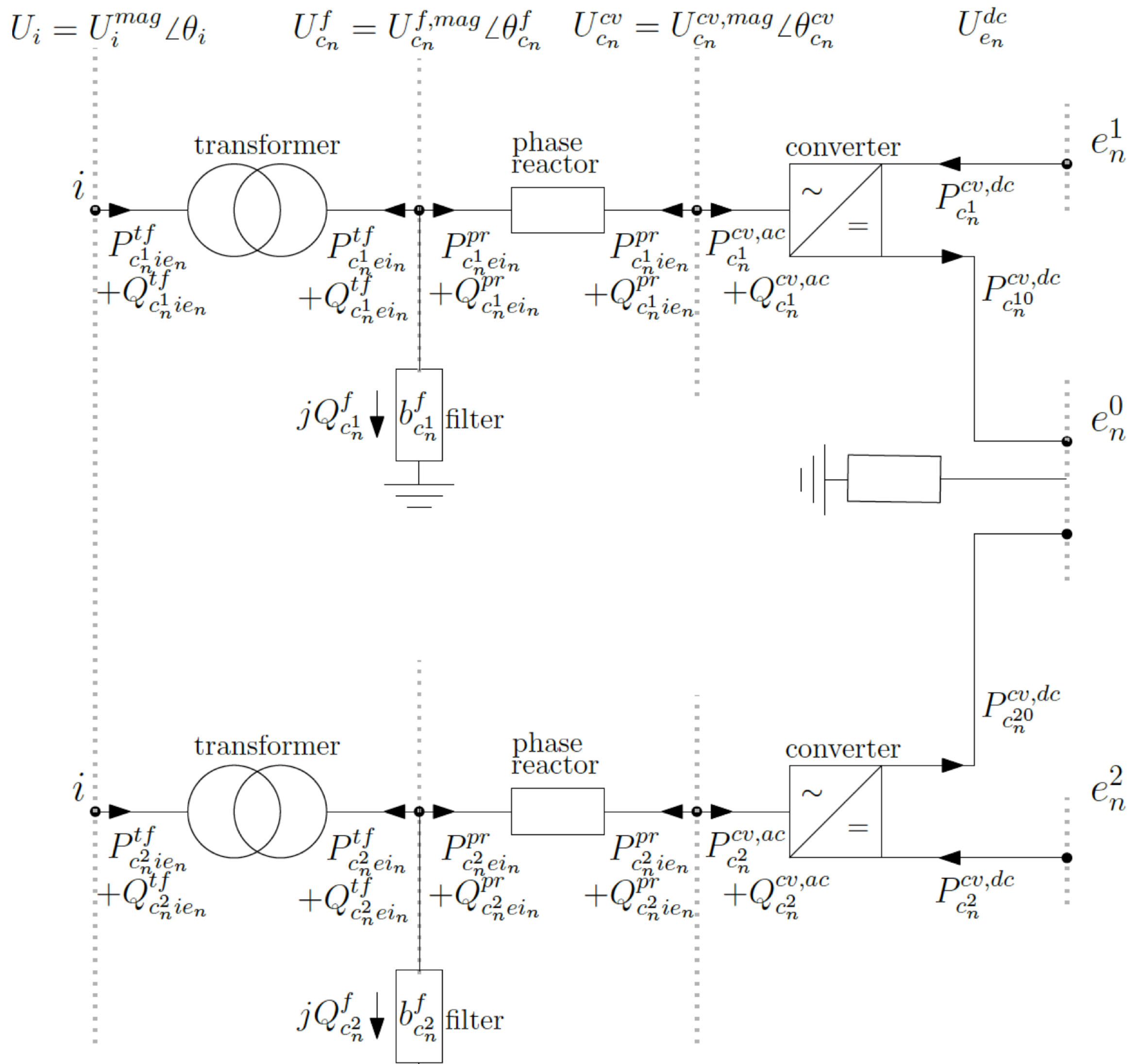


Unbalanced DC grid model:



DC Line

- DC buses ➔ x3 number variables and constraints
- DC branches ➔ x2 or x3 number of variables and constraints
- DC converters ➔ x2 variables and constraints



AC Grid

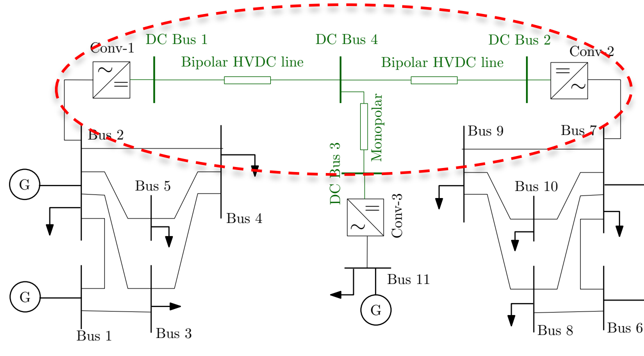
AC/DC Converter station

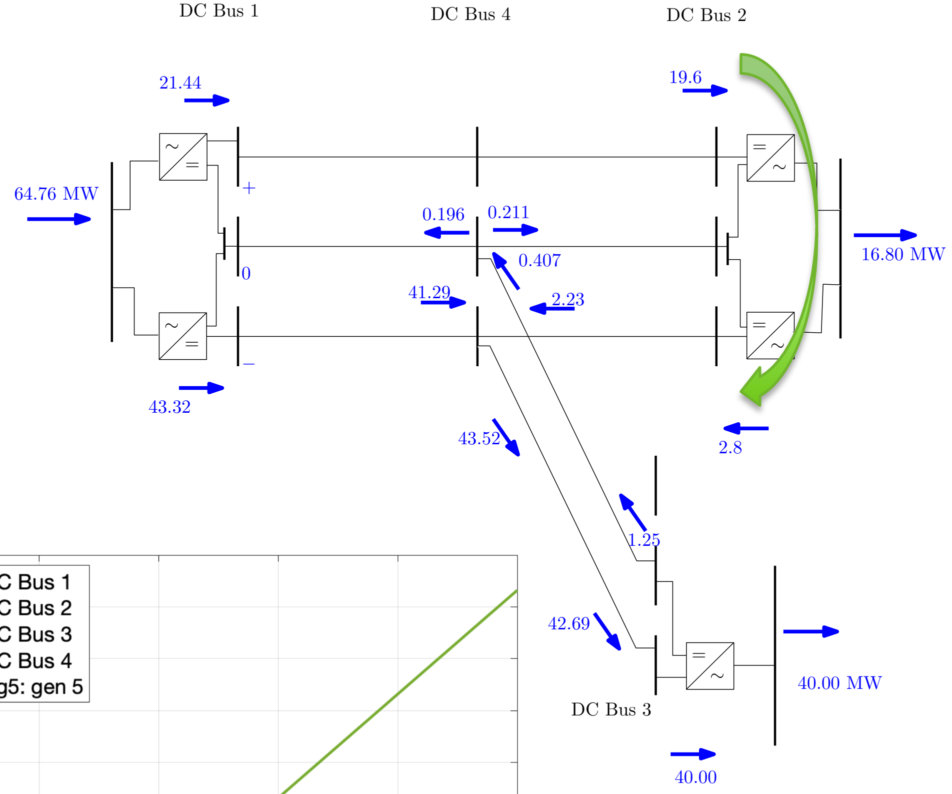
DC grid

Takeaways from the unbalanced OPF model:

Key features of the model:

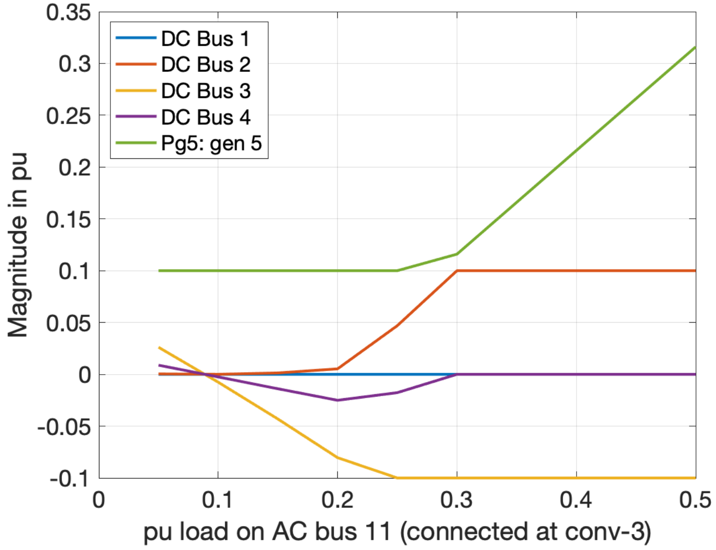
- Explicit modelling of metallic return conductor
- Current-Voltage (I-V) model is implemented for HVDC side: because the common Power-Voltage (P-V) models suffers from numerical instability.





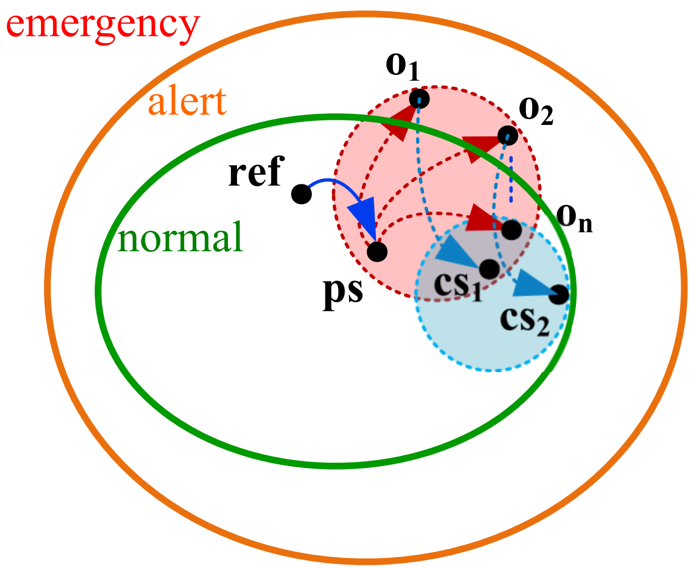
Key observations:

- Power flow through the two poles of a bipolar converter can differ not only in magnitude but also in sign (direction) i.e. "converter loop flows" in extreme cases
- Grounding and metallic return resistance have significant effect on the power flow due to voltage increase in single poles with high unbalance



C. K. Jat, J. Dave, D. Van Hertem, and H. Ergun, "Formulation and Implementation of an Optimal Power Flow Model for Unbalanced HVDC Grids,"[To be submitted].

Incorporating N-1 security: SCOPF

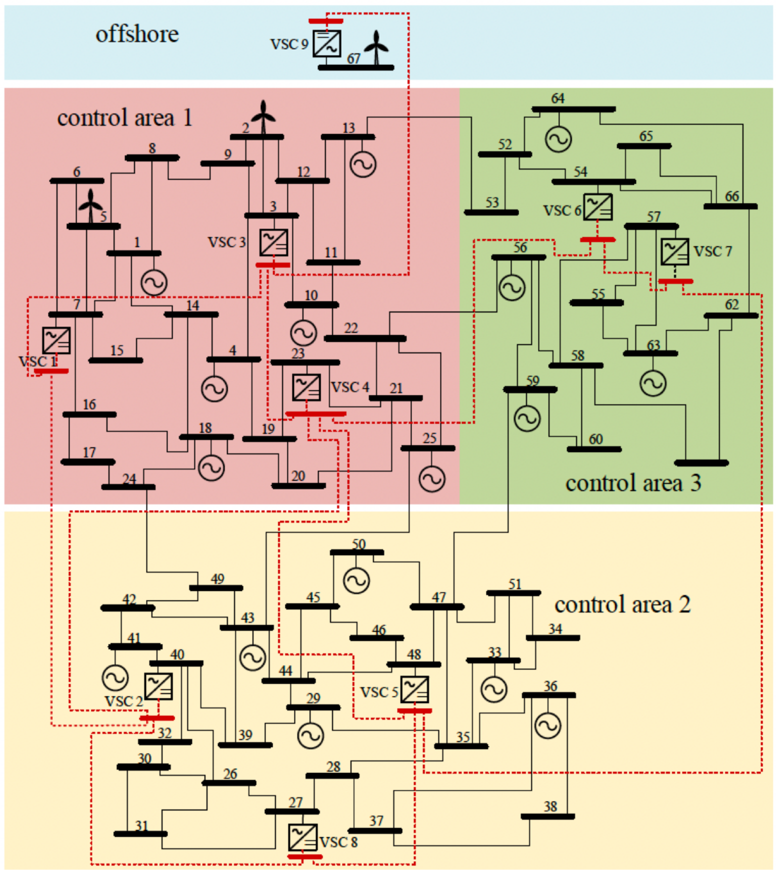


ref: reference state
ps: preventive state
cs: corrective state
o: contingency state

$$min \sum_{g} C_g^{ps} \cdot |\Delta P_g^{ps}| + \sum_{o} \Big(\sum_{l} VoLL \cdot |\Delta P_l^{o}| \Big)$$

Generator redispatch cost

Cost of load shading

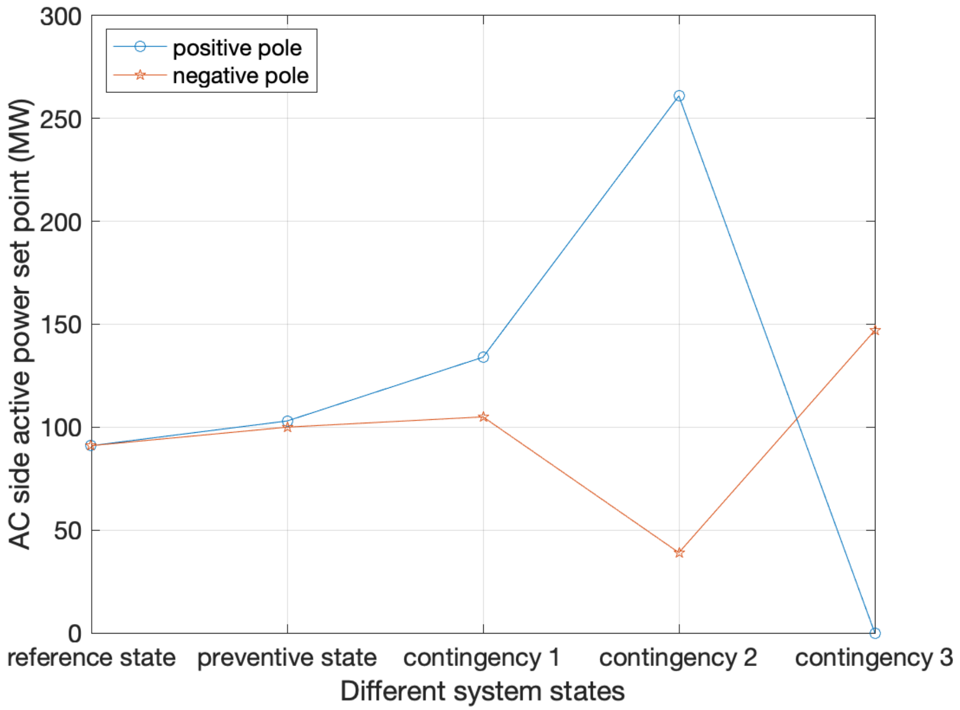


- All HVDC lines and converters ➔ Bipolar configuration
- 11 HVDC line and 9 converters
- 17 conventional and 3 wind generators (2 onshore and 1 offshore)
- The offshore wind station:
  - AC bus no. 67
  - Converter no. 9

C. K. Jat, V. Bhardwaj, H. Ergun, and D. Van Hertem, “A reliability management model for ac/dc grids considering multi-conductor dc grid modelling,”

Key observations from the SCOPF results:

- Operating a bipolar HVDC grid in unbalanced manner in case of single pole outage contingencies, reduces the redispatch cost.
- Exact amount of the benefits depends on the particular contingencies.
- Example test case (with three contingencies): redispatch cost with the unbalanced operation is almost half compared to when only balanced operation is allowed.
- The set points for positive and negative poles of the same converter can vary significantly under different contingencies.



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Conclusions

- An optimal power flow (OPF) model for unbalanced operation of HVDC grids is introduced using a multi-conductor representation of the DC grid.
- The OPF model is extended to incorporate N-1 security criteria resulting security constrained OPF (SCOPF) model.
- The unbalanced operation of the HVDC grid under contingency can have significant savings in operational costs due to utilization of HVDC flexibility.
- Future work → optimal design of mixed HVDC configurations.

Neptune

Thank you for your attention!

With the support of the Energy Transition Fund

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FOD Economie, K.M.O., Middenstand en Energie

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