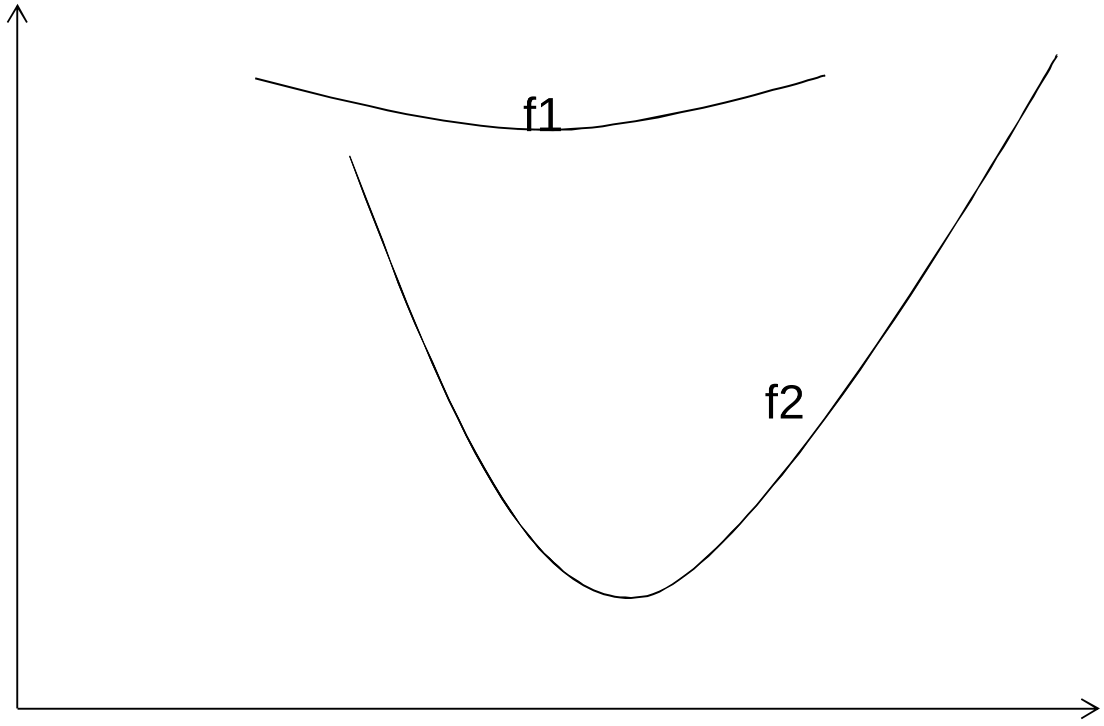
Xiaoming Feng, ABB, June 26, 2013

HVDC Grid Technology - Benefits and Impact on Optimal Power Flow Modeling Considerations

FERC Tech Conference June 24-26, 2013

Optimality and Optimizability



- f2 is more optimizable than f1
- A suboptimal solution on f2 produces more return than optimal solution on f1
- Making the system more optimizable (controllable) is equally important to solving the system to optimality

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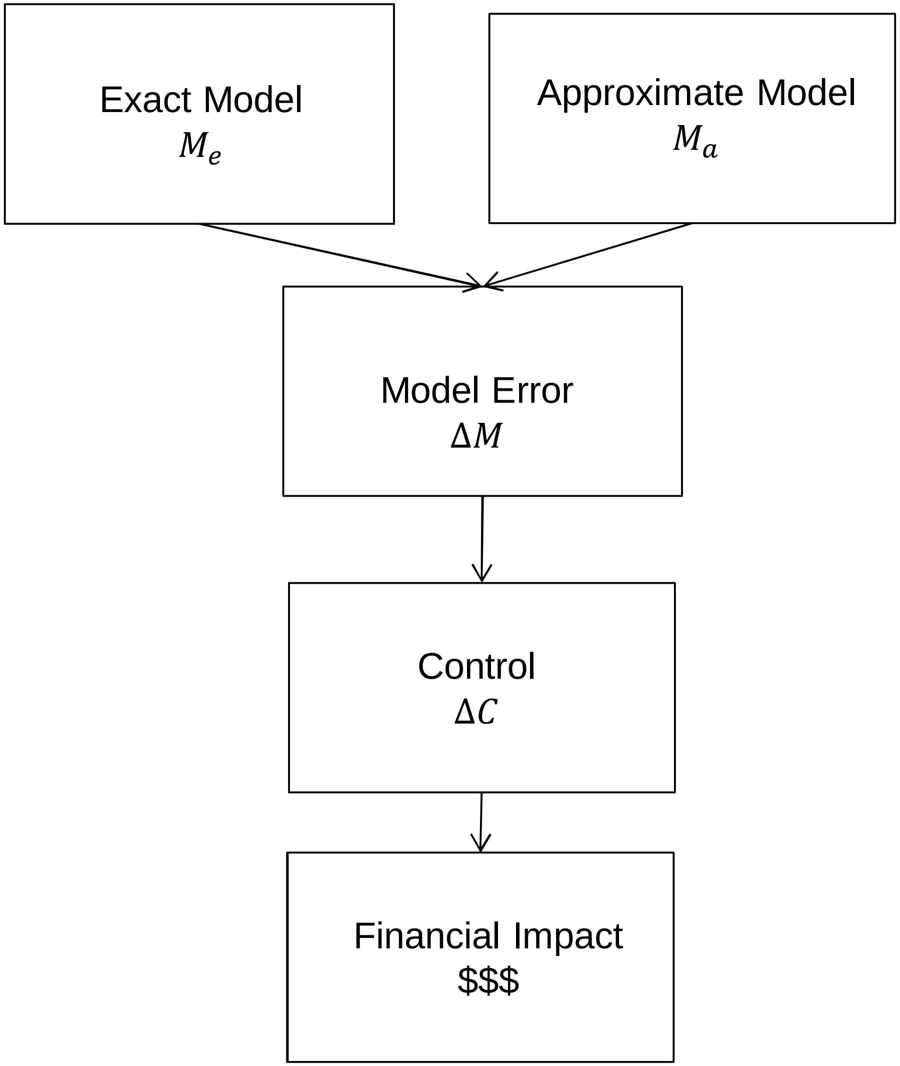
Role of model in model based control

- Make sense of the system condition
- Predict how the system condition is evolving
- Answer what if questions
- Predict the consequence of control actions and optimize controls strategies

- Quality of control depends on quality of system model (both the system behavior and the operation environment)

Motivation to Use Higher Fidelity Model

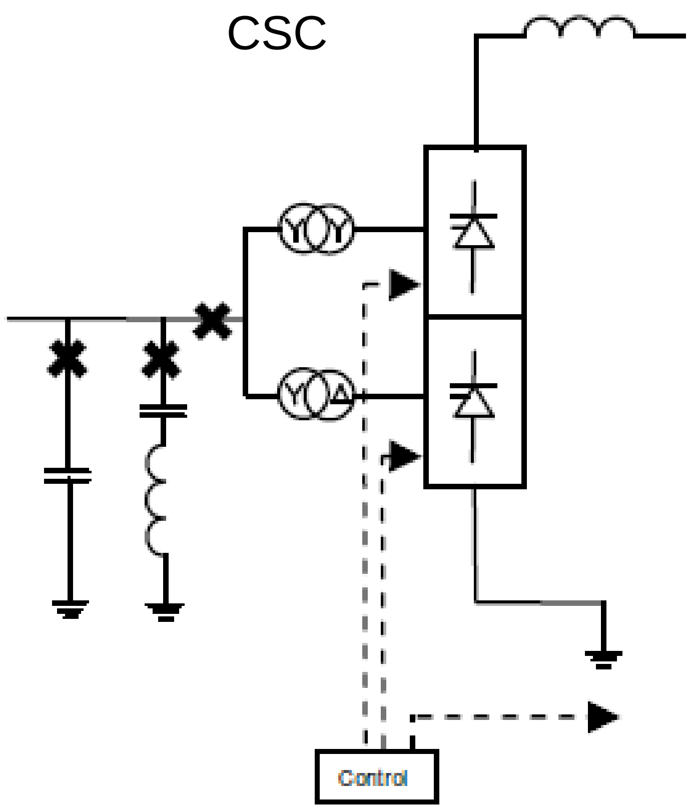


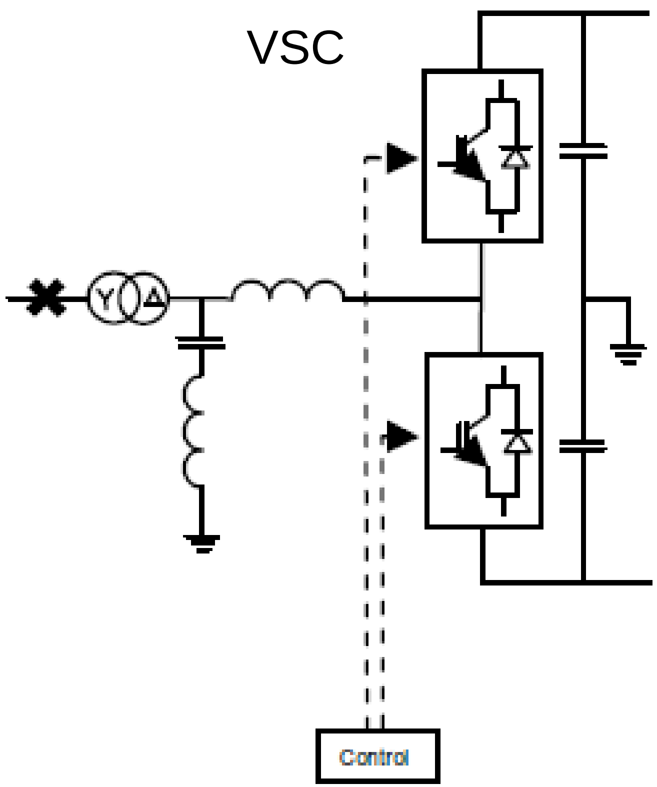
The power grid is AC, correct?

- Not entirely
- The grid of the future will have more DC
- DC modeling can not be ignored or done as an inconvenience or exception

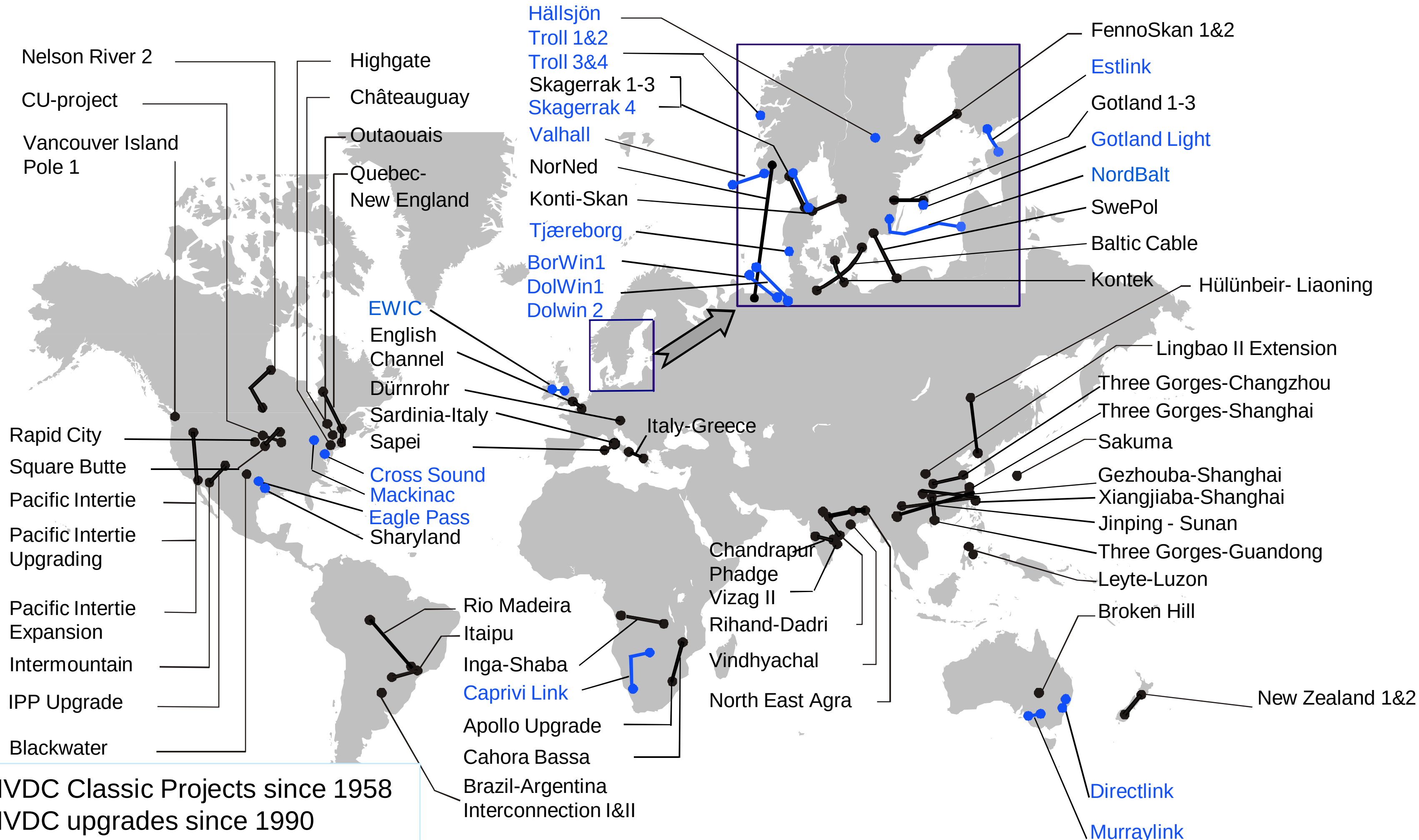
HVDC Technology - CSC and VSC HVDC

- CSC – Current source converter, thyrister based
- VSC - Voltage source converter, IGBT based



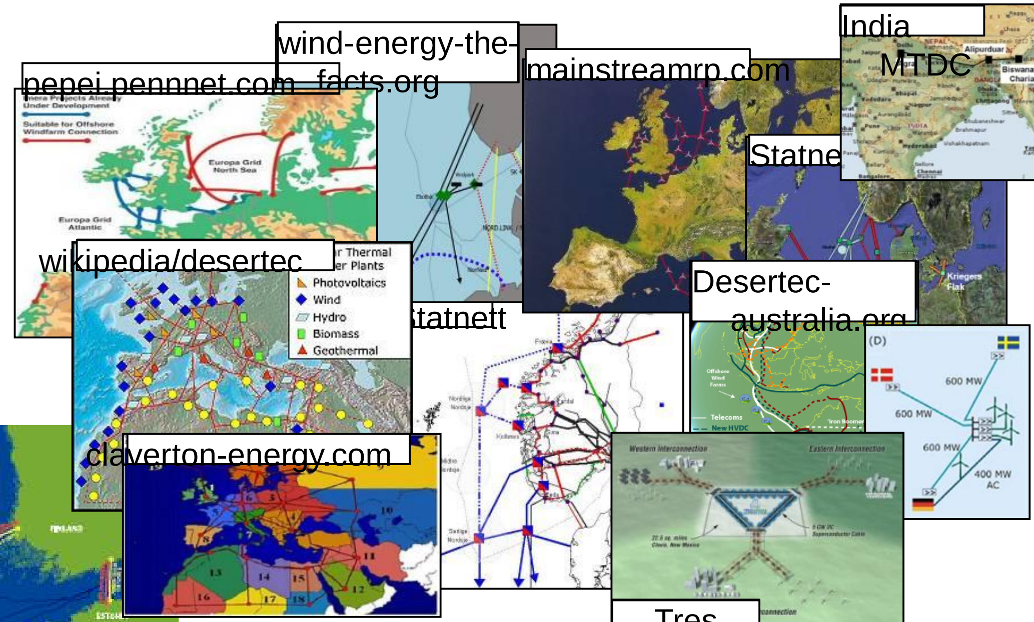


Numerous HVDC projects and growing

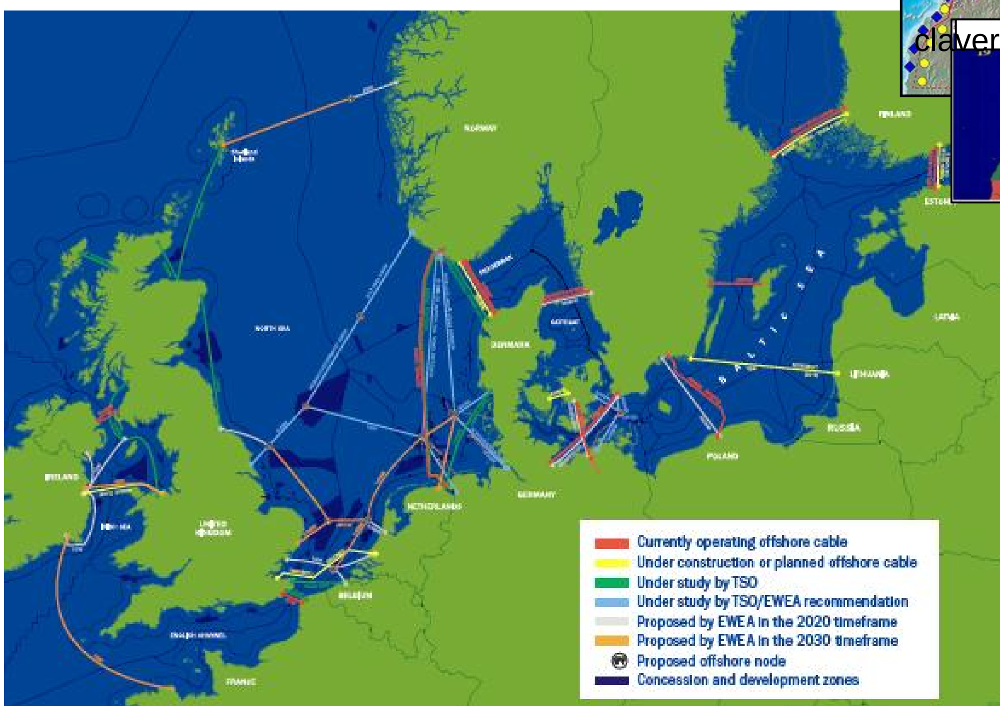


58 HVDC Classic Projects since 1958
14 HVDC upgrades since 1990
19 HVDC Light Projects since 1997

Increasing controllability by HVDC- Trend to MTDC



Tres Amigos



EWEA 20 Year Off Shore Network Master Plan (2009)

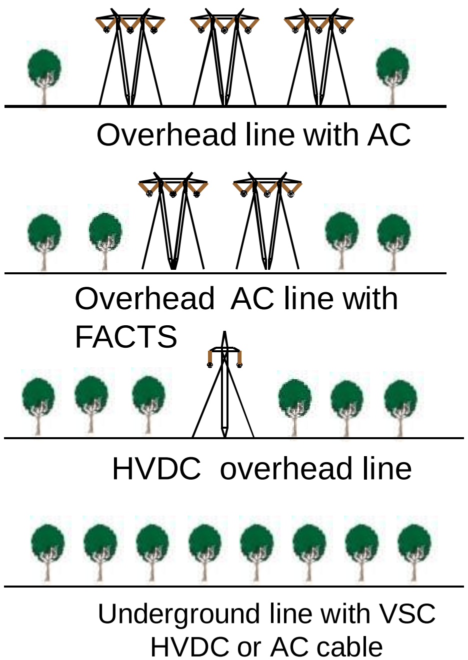
Why DC Transmission

- High power long distances overhead or underground cable
- Low transmission losses over long distances
- Submarine cables over long distances. connection of remote offshore wind power
- Connection of asynchronous grids
- Full control of power flow (4 quadrant control by VSC)
- Grid stability enhancement
- Black start
- Small footprint for HVDC when overhead lines
- Negligible magnetic fields compared with AC

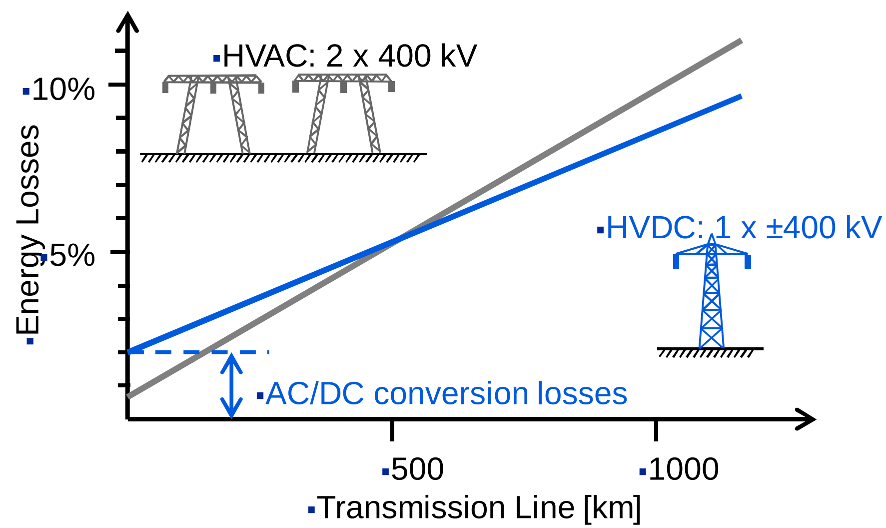
Benefits of HVDC vs. HVAC

Different technologies:

Same power transmitted



- Higher transmission capacity
- Possibility to use underground and subsea cables
- Lower losses on long distances



<u>VSC HVDC*</u>

- 1 x ±400 kV
- 1200 A
- 1620 mm^2 conductors

<u>HVAC</u>

- 2 x 400 kV
- 2 x 1200 mm^2 conductors

*Voltage Source Converter : High Voltage Direct Current

HVDC technology development
More power and lower losses

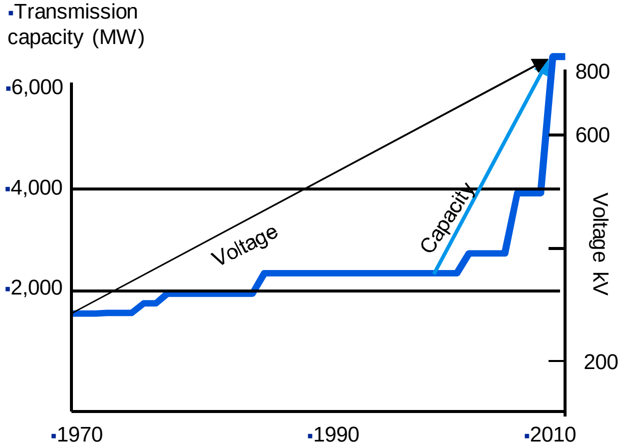
Capacity up 6 times since 2000;

Voltage up from +/- 100kV to +/- 800kV since 1970

Xiangjiaba - Shanghai
± 800 kV UHVDC.

World's most powerful link commissioned

▪HVDC Classic



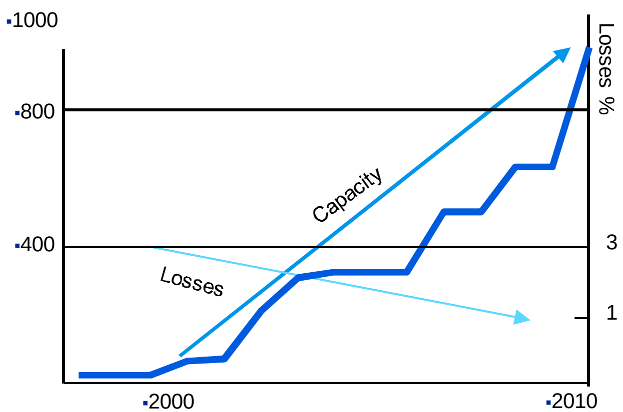
6400MW over 2000 km at +/- 800 kV

Capacity up 10 times; losses down from 3% to 1% per converter station since 2000

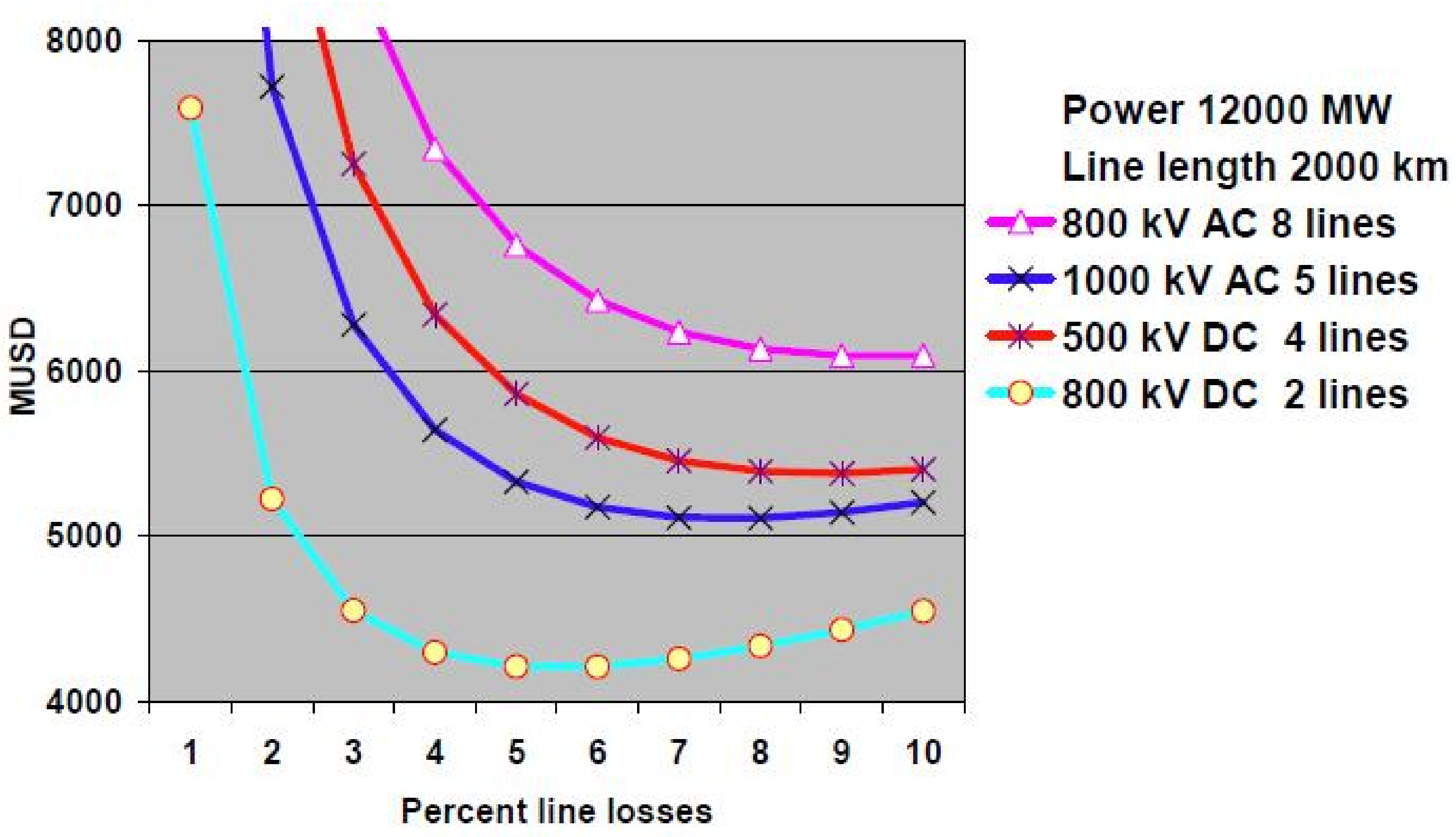
BorWin:
400 MW, 200km subsea and underground

World's most remote offshore wind park

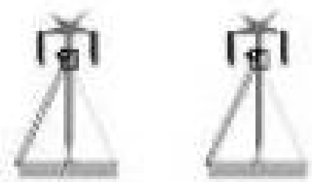
▪HVDC Light



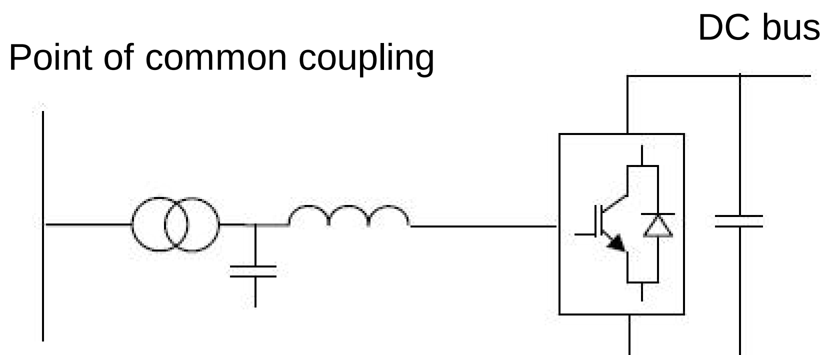
Line loss comparison



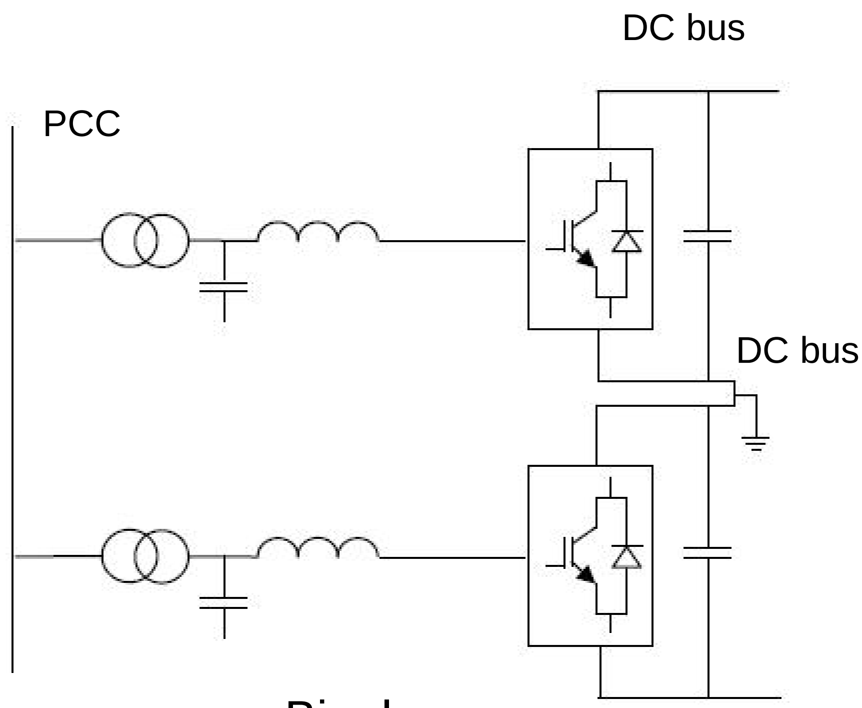
ROW Requirement for 6000 MW Transmission Line

	765 kV AC	500 kV DC	800 kV DC
Number of lines:			
Right of way (meter)	~ 240	~ 110	~ 90

Configurations of VSC HVDC

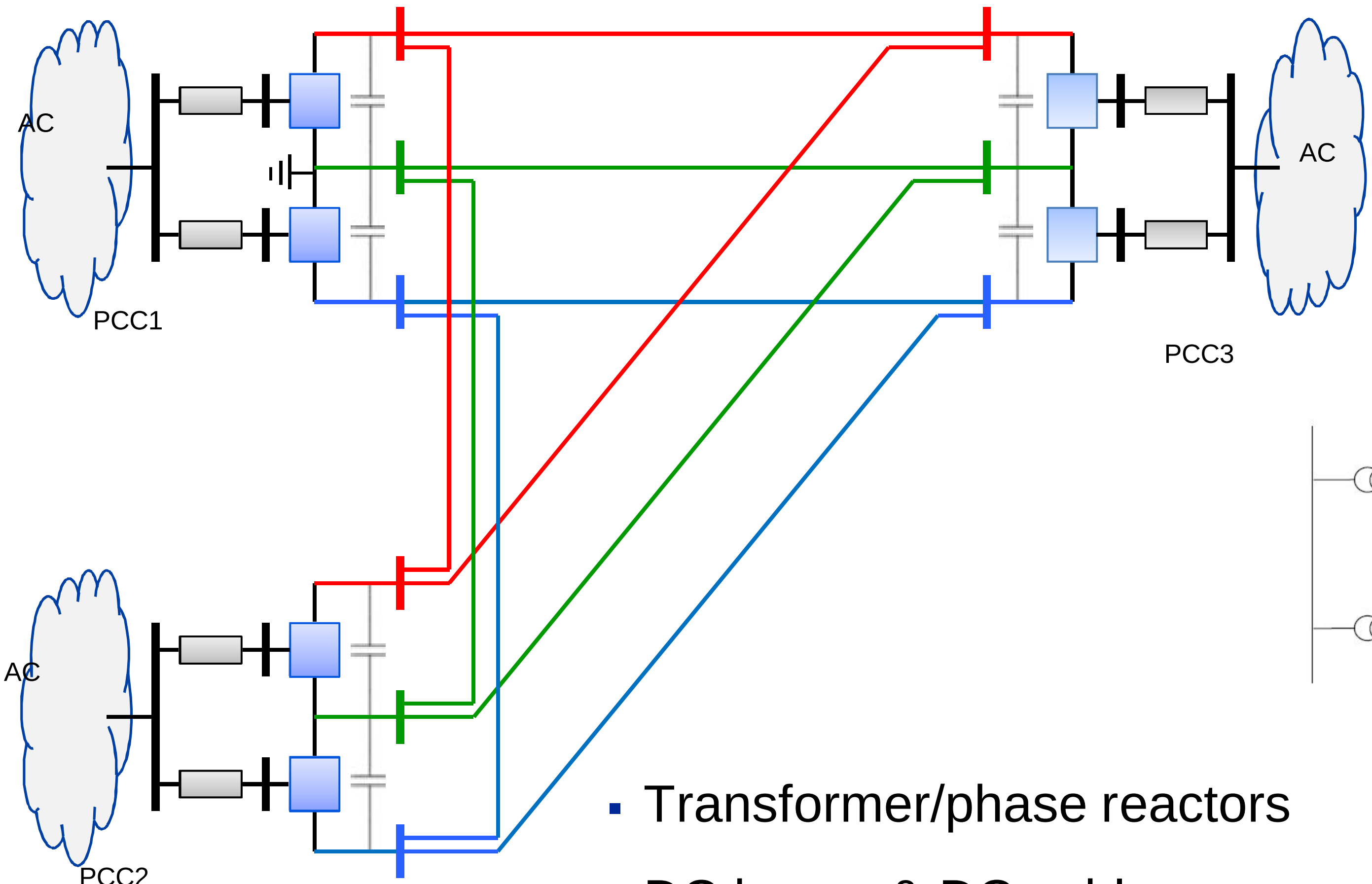


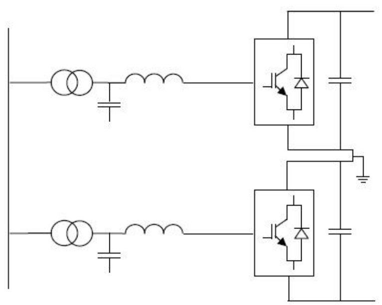
Monopole



Bipole

A three terminal DC Grid

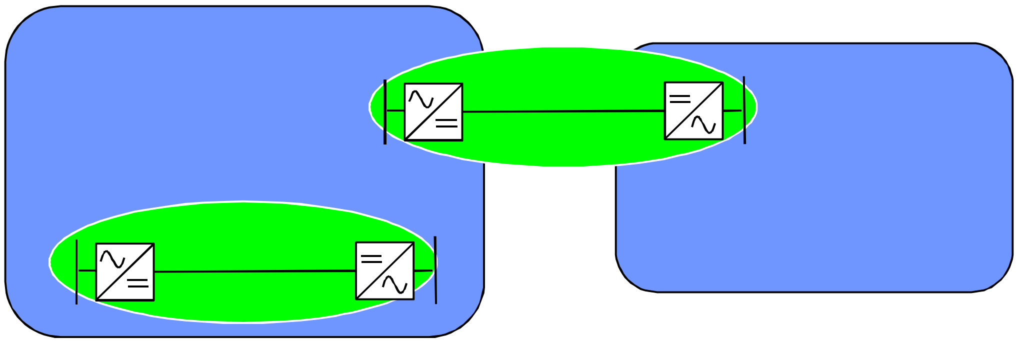


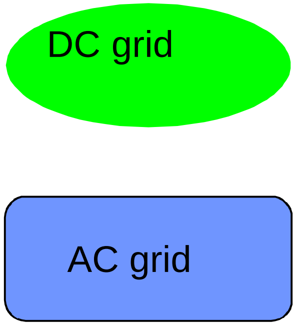


- Transformer/phase reactors
- DC buses & DC cable network/grounding resistors
- AC/DC converters

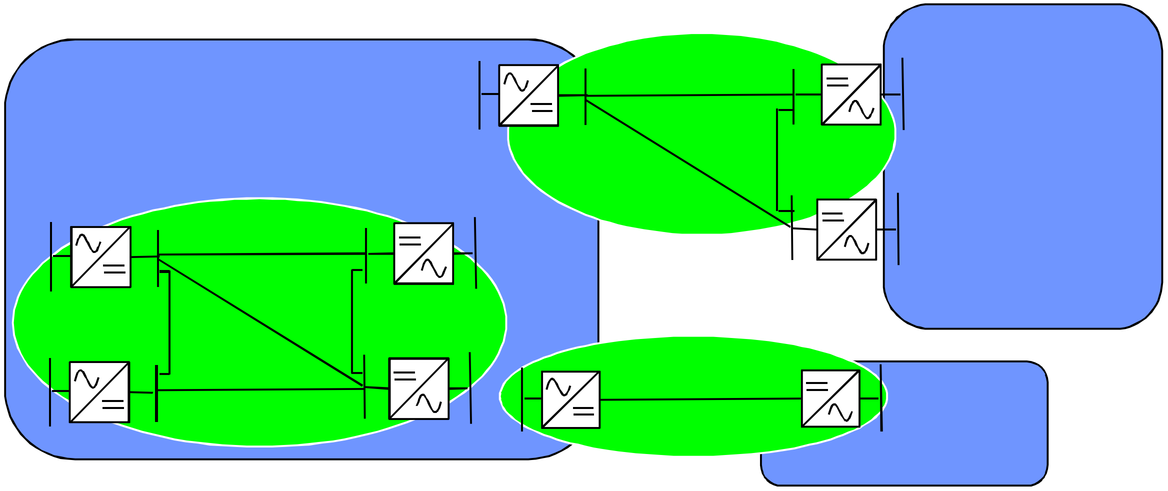
The evolving power grid

AC grids with P2P (point to point) DC links



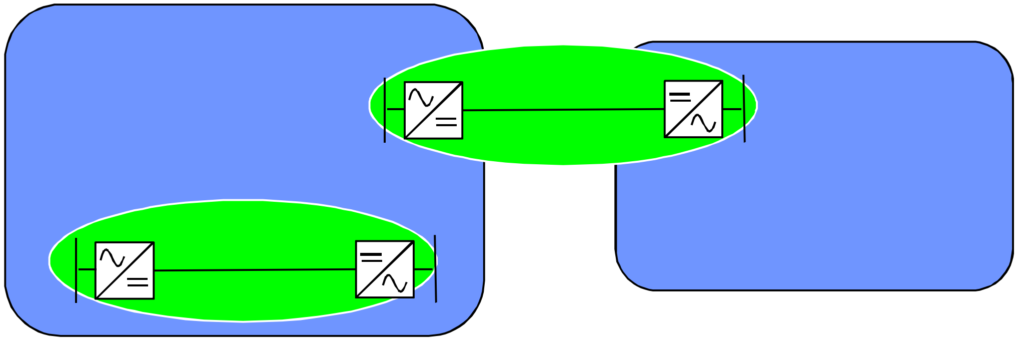


AC grids embedded or interconnected with MTDC grids



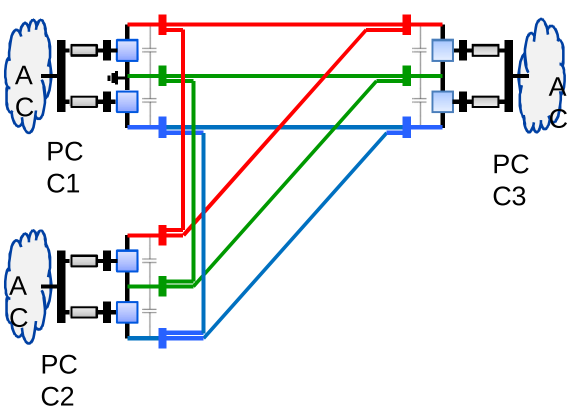
MTDC Grid needs a generalized approach

- Traditional approach for P2P DC link is to model it as equivalent power injection pair at the connecting AC buses
- This is not adequate for DC grid modeling in power flow, contingency analysis to account for different operating configurations



DC Gird Modeling

- Transformer/phase reactors – same model as in AC OPF
- DC buses & DC cable network/grounding resistors - KCL / KVL equations for resistive network)
- More controls – PQ set point, slack converter DC voltage
- AC/DC converters
  - Loss modeling, f- non linear converter loss function
  - $P_{AC} + P_{DC} = f(converter\ state)$
  - Operating limit (valve current, DC voltage …)
- Loss model is not standardized



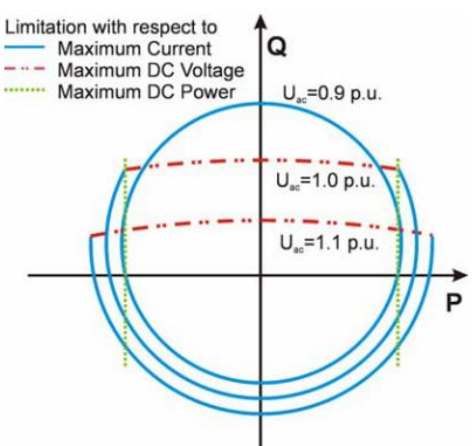


Figure 1 **The capability curve**

Impact on the system model

- The number of equation types increased
- No longer a simple choice between rectangle or polar formulation
- Non linear converter model does not lend itself to IV formulation simplification

Summary

- For smart grid to be effective, power flow controllers are necessary (Optimizability is as important as optimality)
- Higher fidelity model is needed for feasibility as well as optimality
- Future grid will be a mix of AC and DC technologies
- Full “AC” OPF needs to adopt high fidelity model for AC as well as DC, new algorithm/formulation must be designed considering this requirement

- Question?

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