Multi-terminal HVDC – The future power grid

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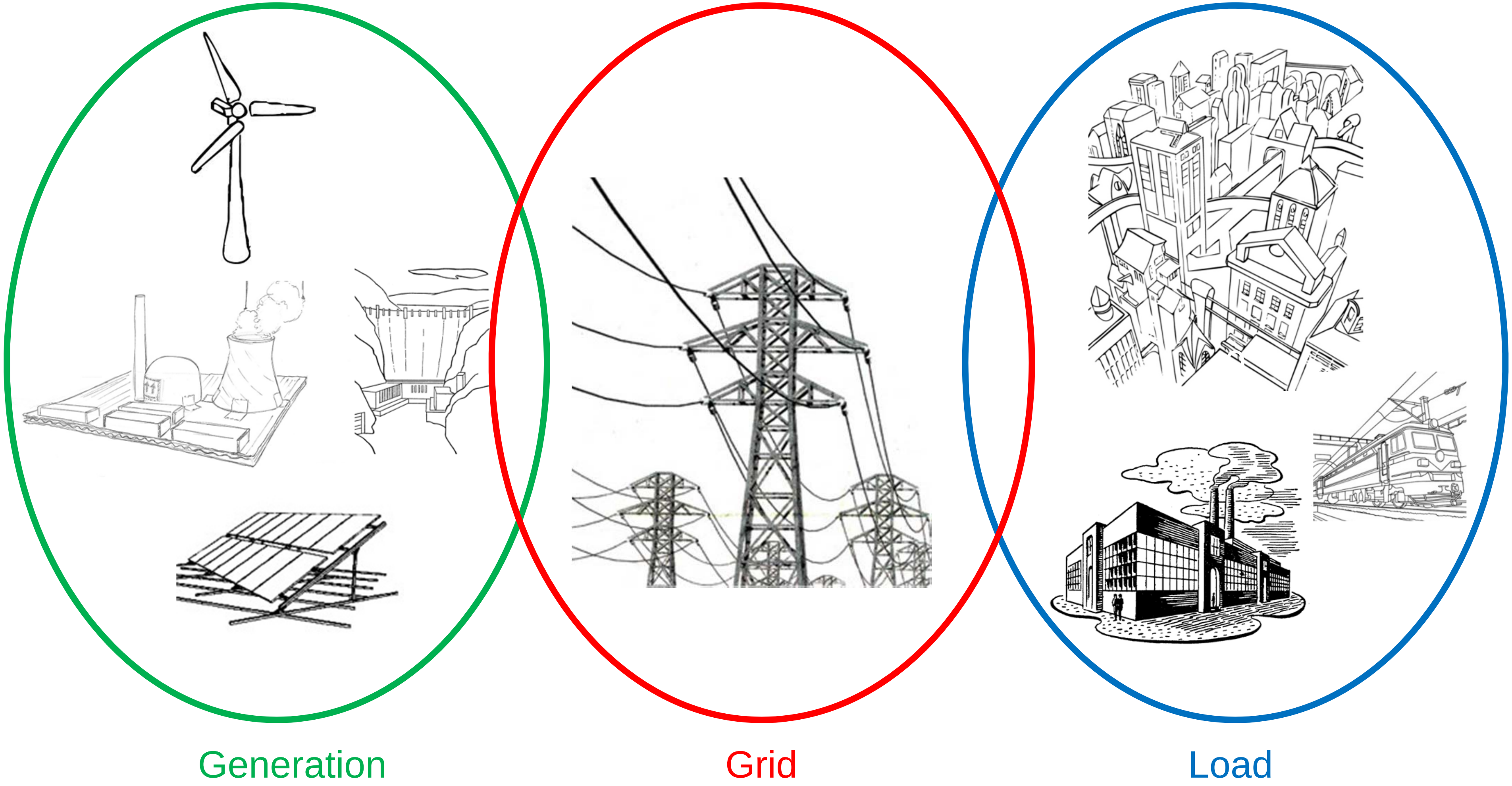
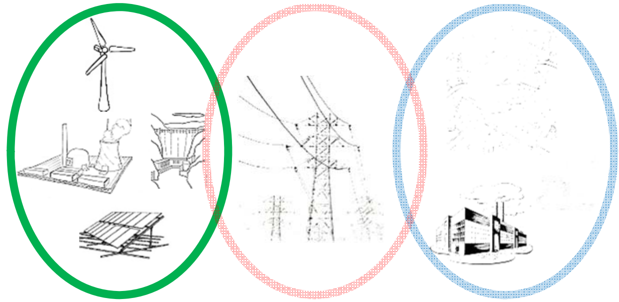
Motivation



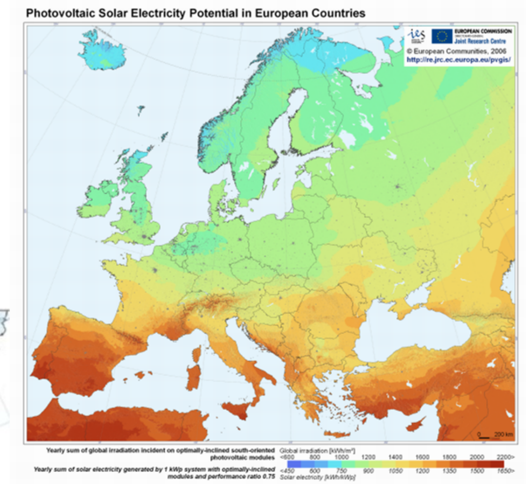
Agenda

- Motivation
- Why HVDC?
- Operation of a combined HVAC and HVDC grid
- Conclusion

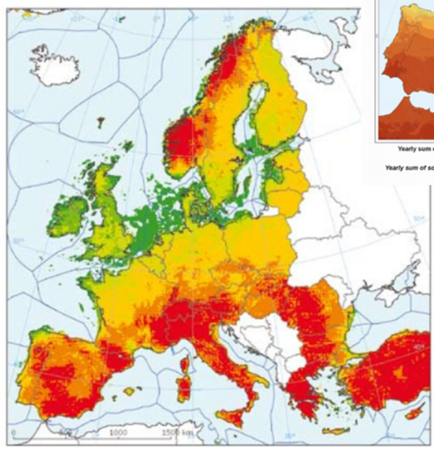
Motivation - Generation



- Shift in production time, RES
  - Weather dependent production
  - Store energy at peak production, noon

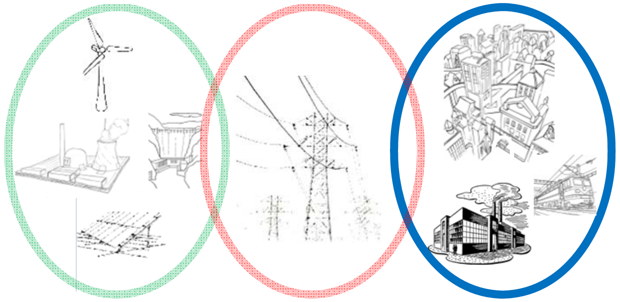


- Shift in placement, RES
  - Weather dependent places



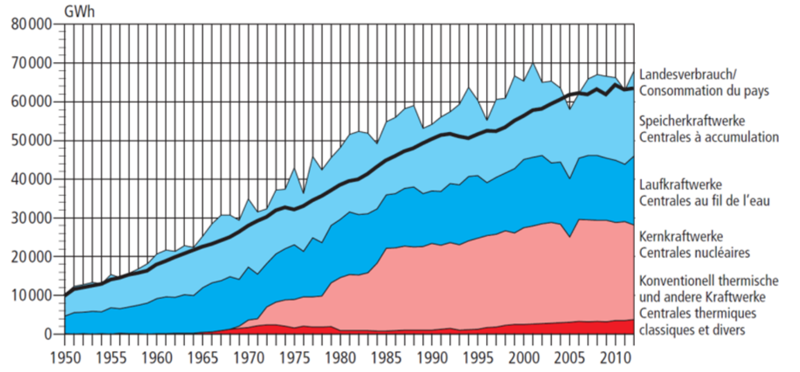
Source: EEA, 2008.

Motivation - Loads



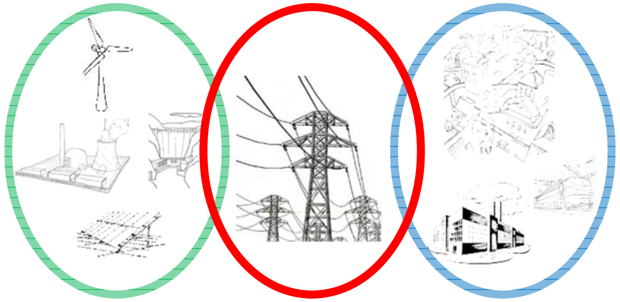
- Geographical stable
- Limited flexibility in time
  - Controllable loads
- Increasing load level
  - Population growth
  - Economical growth
  - Technological change

Stromproduktion der Schweiz nach Erzeugerkategorien seit 1950
Production d'électricité de la Suisse selon les catégories de production, depuis 1950



Quelle: BFE, Schweizerische Elektrizitätsstatistik 2012
Source: OFEN, Statistique suisse de l'électricité 2012

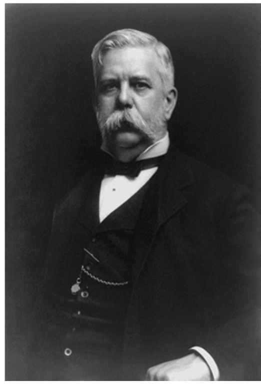
Motivation - Grid



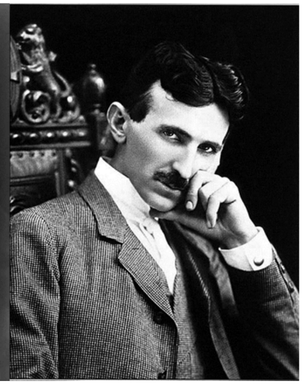
- Connector
  - Strongly depend on load and generation
- Peak covering
  - Transmission grid is constructed to handle peak power transfer
- Replacement
  - Average age >40 years
  - Cable connections

Why HVDC? – War of Currents

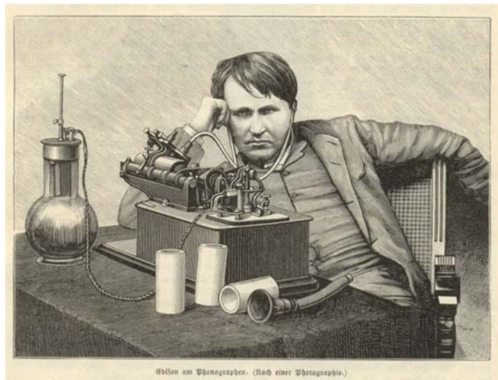
- Second half of 19th century
  - Different people and companies involved in Europe and USA
- First transmission line DC
  - 1882 at Miesbach – Munich, 25%
- First AC transmission line incl. transfo.
  - 1891 at Lauffen – Frankfurt, 75%
- Revival of DC transmission
  - 1954 at Västervik – Ygne (Gotland, Sweden)
  - Current source converter



Westinghouse

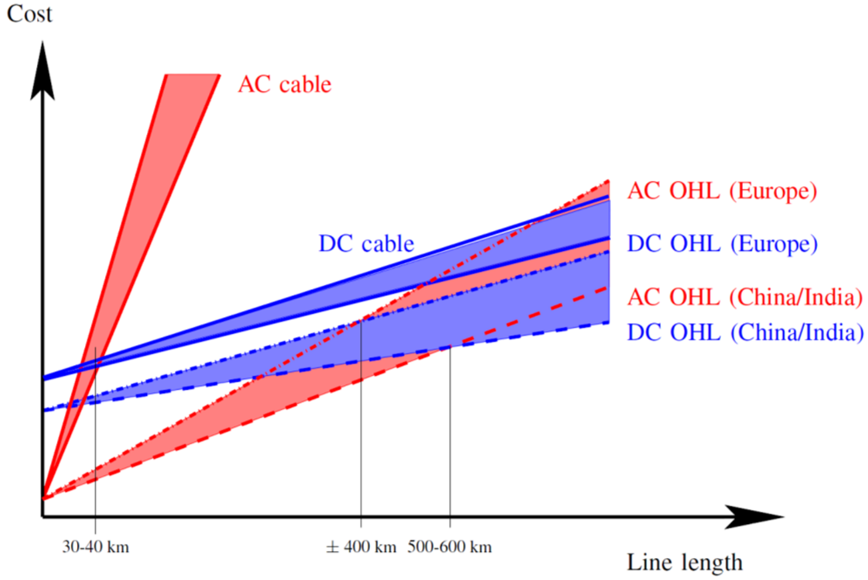


Tesla

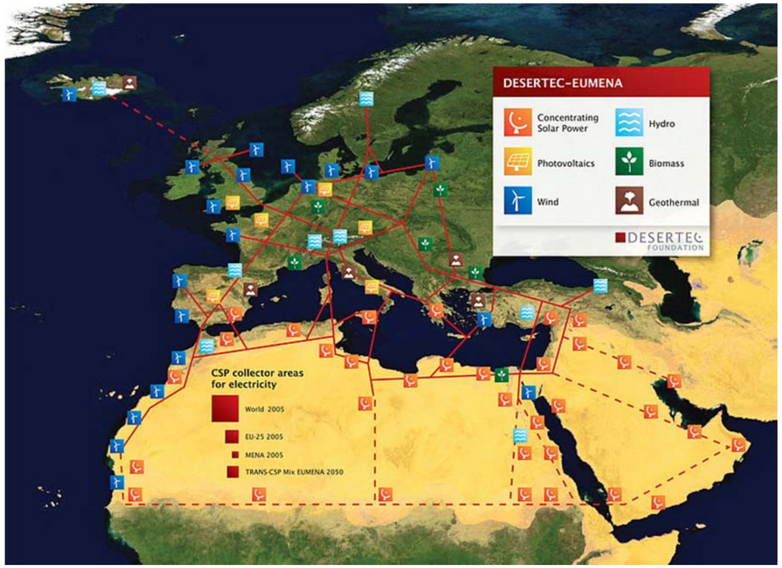


Edison

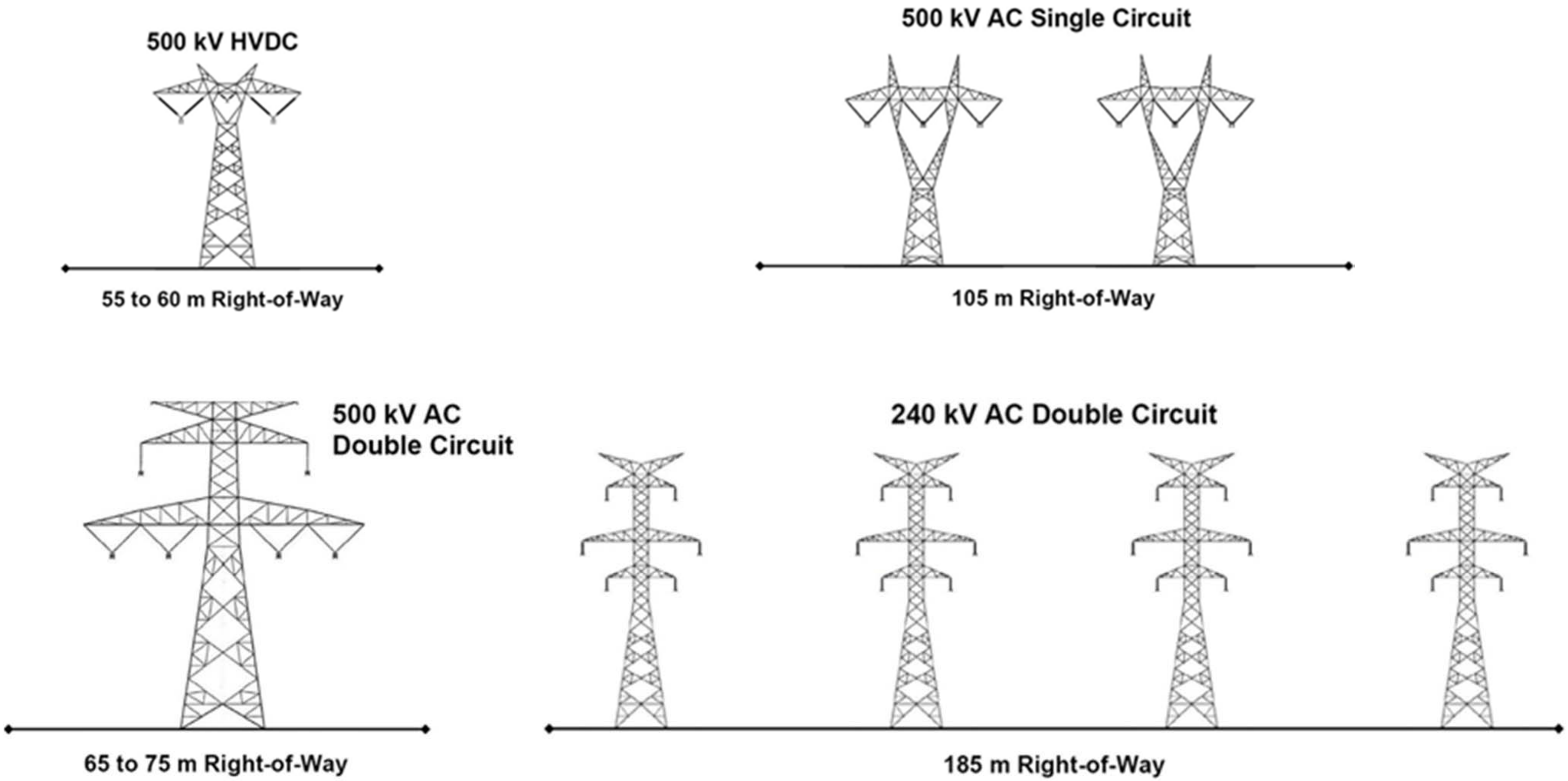
Why HVDC? - Advantages



- More efficient
  - No skin effect
  - No proximity effect
- Long AC cables have high charging currents
- No varying electromagnetic field
- Inherent active power control
  - Flexibility
- Combine non synchronous grids



Why HVDC? – Land Use Impact



Why HVDC? - Challenges

- Conversion losses
- Costs
- “Young” technology
- DC breaker
- **Operation of Multi-termial HVDC grids**

Why HVDC? – CSC vs. VSC

	Current Source Converter (CSC)	Voltage Source Converter (VSC)
Power capability	High	Medium
Harmonics	Filters required	No filters required
Station losses	<1 %	~1%
AC system requirement	Strong	Weak
Reactive power	Dependent on active p.	Controllable
Black start capability	No	Yes
Cost	1	1.1-1.15
Changing of voltage polarity for power reversion	Required	Not required

Why HVDC? – Actual project

- In operation: ~Summer 2014
- 2x1000 MW, VSC
- ±320 kV DC
- 64.5 Km (8.5 Km tunnel)
- 700 Mio. €
  - 5-10 x OHL costs

Operation of a combined HVAC and HVDC grid - MTDC-What is the Preferred Topology?

- Influence of network topology on three aspects: steady-state losses, maximum transient fault currents, and post-fault contingencies
- Simulations in large combined AC/offshore DC network
- 4 DC network layouts, 3 fault locations

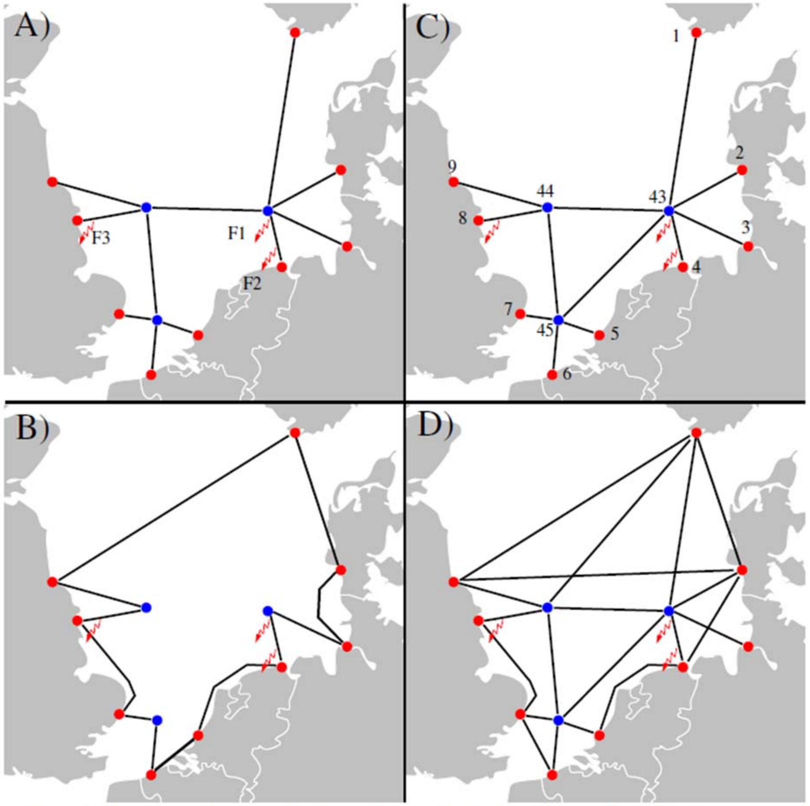


Fig. 5. DC network topologies: A) radial, B) ring, C) lightly meshed, D) densely meshed

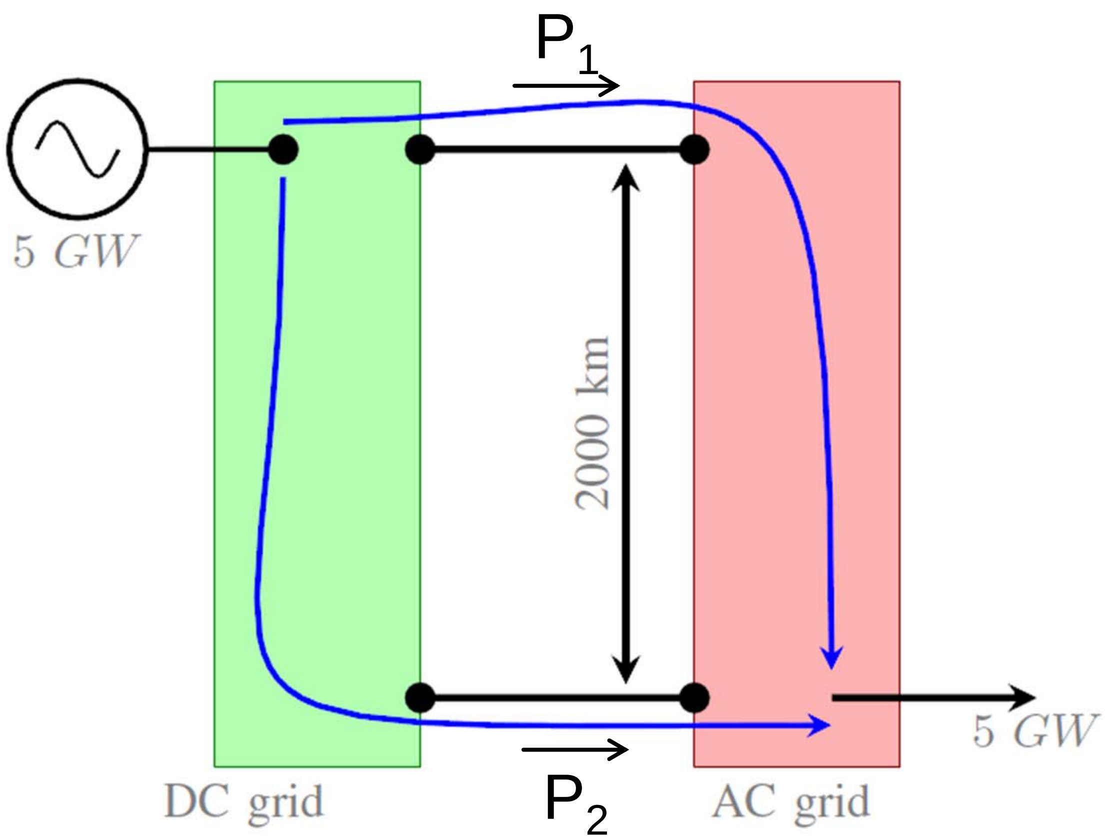
Operation of a combined HVAC and HVDC grid - MTDC-What is the Preferred Topology?

- Conclusion:
  - Comparison of performance:
    - Operation cost for OPF
    - Maximum short circuit current for failure

	Pre-Fault OPF	F1	F2	F3	Post-Fault OPF
Radial	3	2	2	3	4
Ring	4	1	1	1	2
Lightly Meshed	2	3	3	2	4
Densely Meshed	1	4	4	4	1

1 = best, 4 = worst

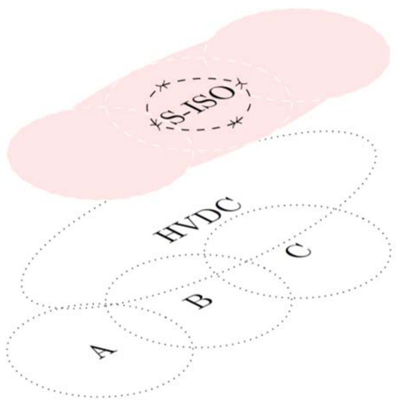
Operation of a combined HVAC and HVDC grid - Optimal Power Flow Control?

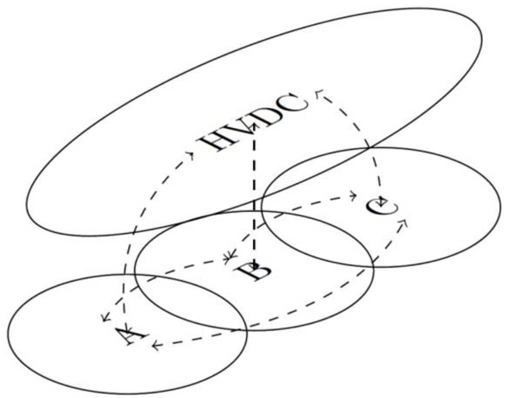


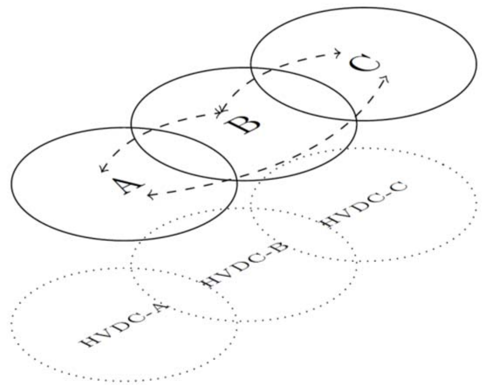
Operation of a combined HVAC and HVDC grid - Optimal Power Flow Control?

- Operating Schemes

Super ISO	HVDC ISO	Distributed AC & DC ISO







Super ISO

\+ Optimal (OPF) solutions
\+ Full knowledge

\- Complex system

HVDC ISO

\+ Focus
\+ No major changes for existing ISO/TSO

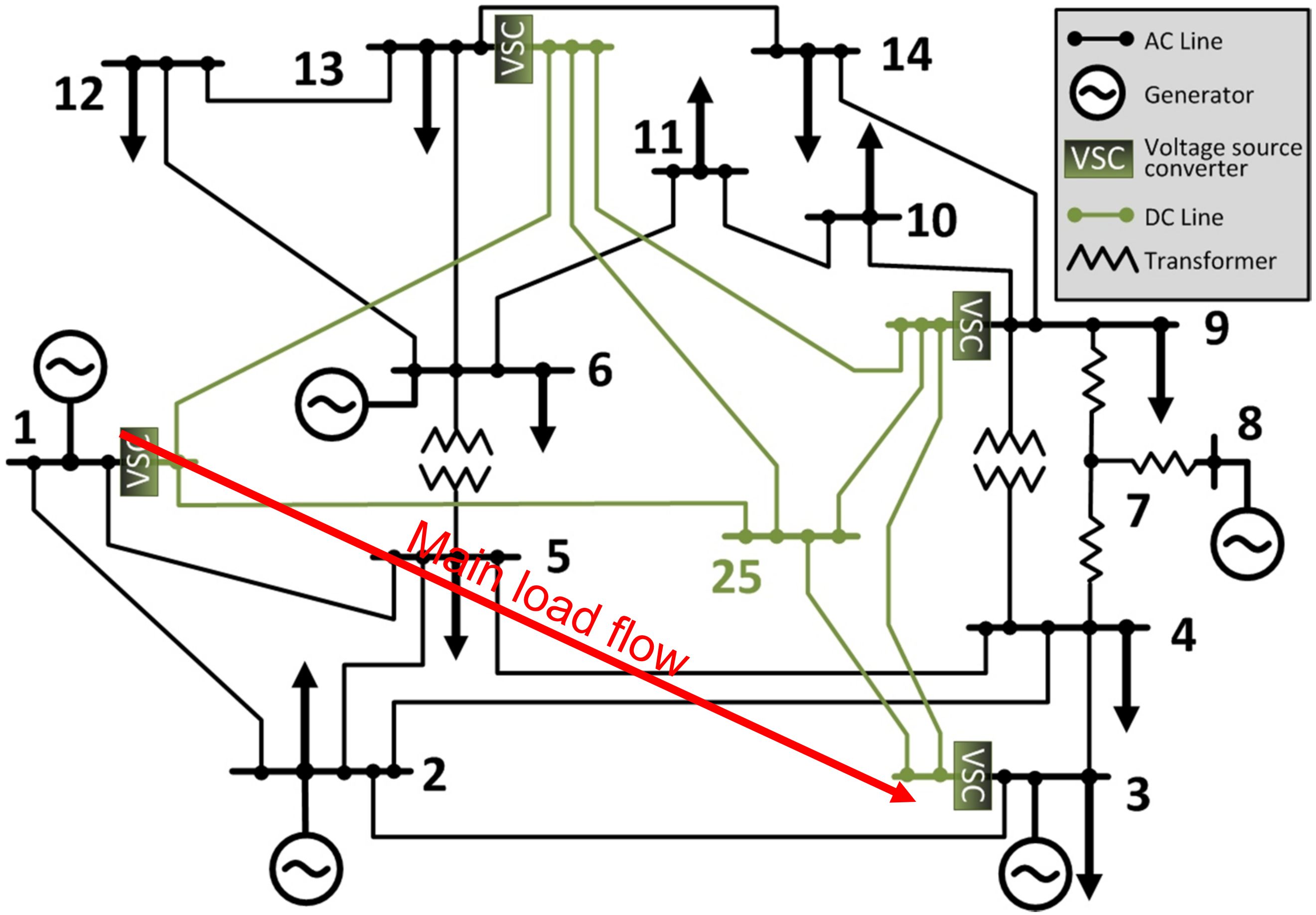
\- Near optimal solution
\- Reduced system knowledge

Distributed AC & DC ISO

\+ Existing borders
\+ Legal boarders

\- Near optimal solution
\- Increased communication needed

Operation of a combined HVAC and HVDC grid - Optimal Power Flow Control?



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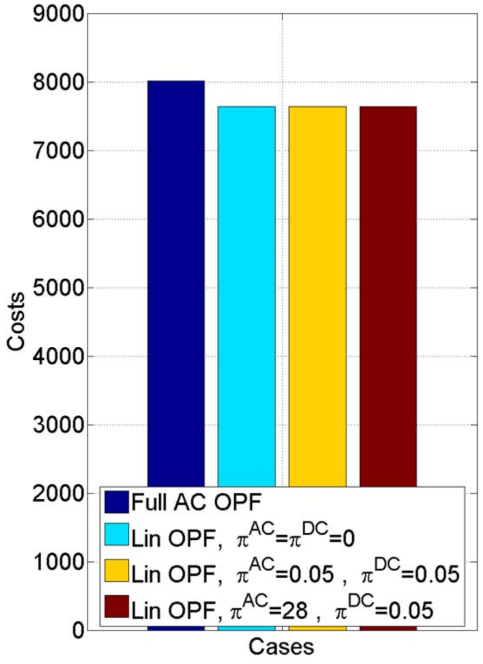
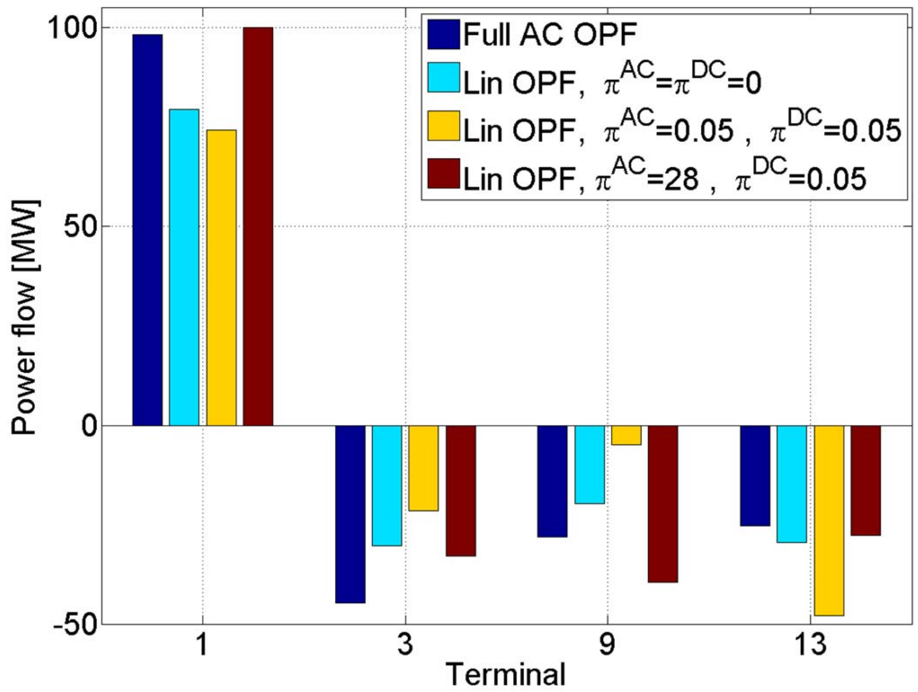
Operation of a combined HVAC and HVDC grid - Optimal Power Flow Control?





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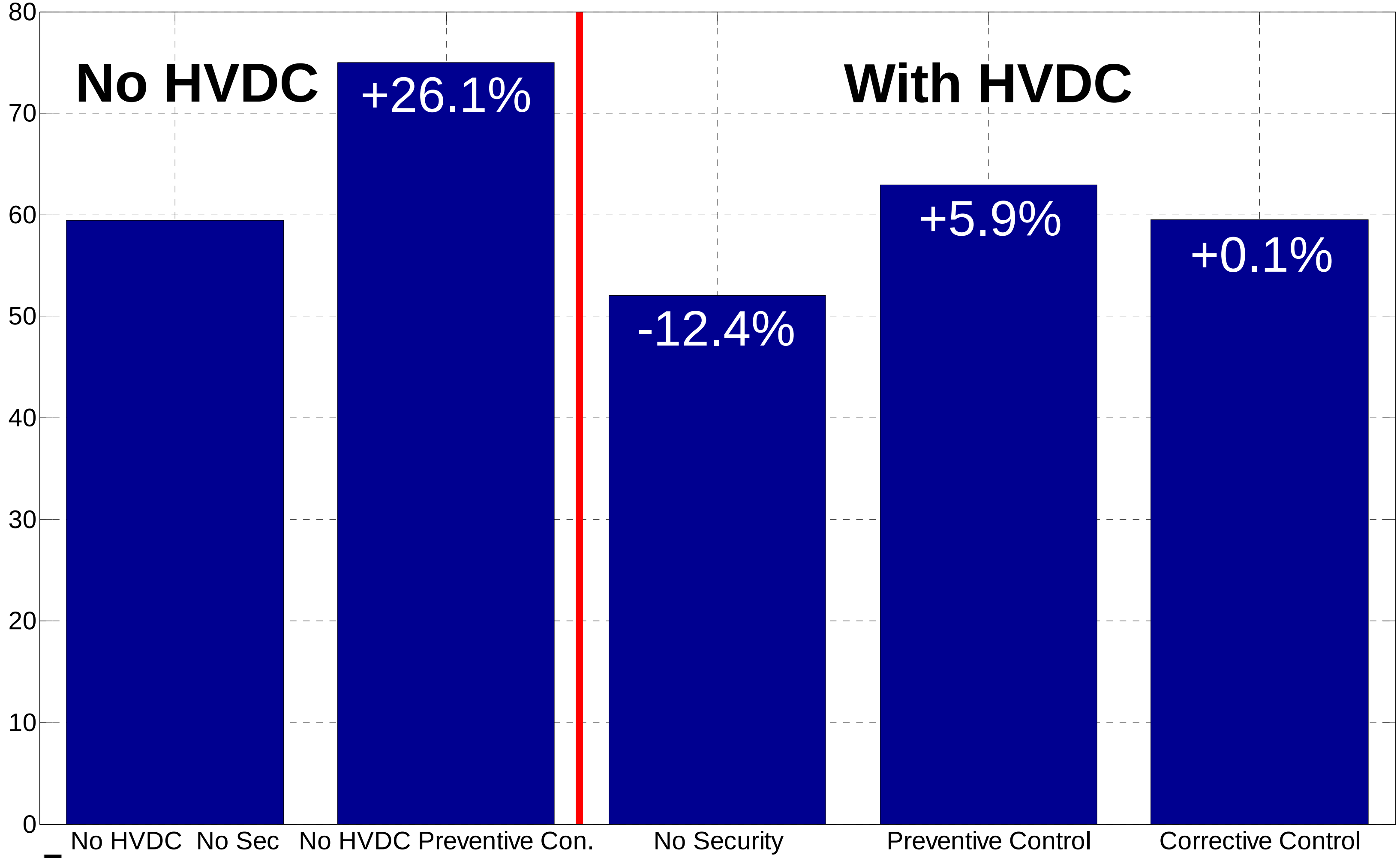
Operation of a combined HVAC and HVDC grid - Optimal Power Flow Control?

- Including security into the model
  - N-1 criterion
    - AC line outage
    - DC line outage
    - Generator outage
    - Load outage
    - Converter station outage

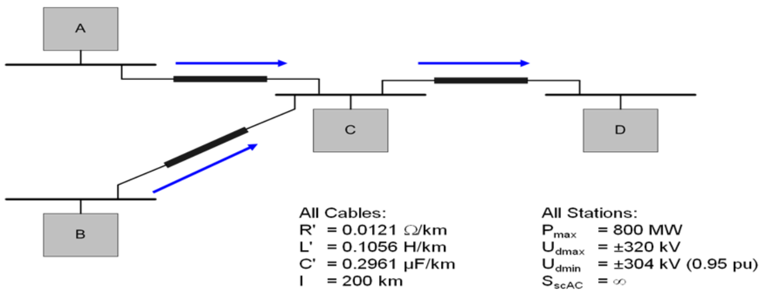
- Preventive and corrective method

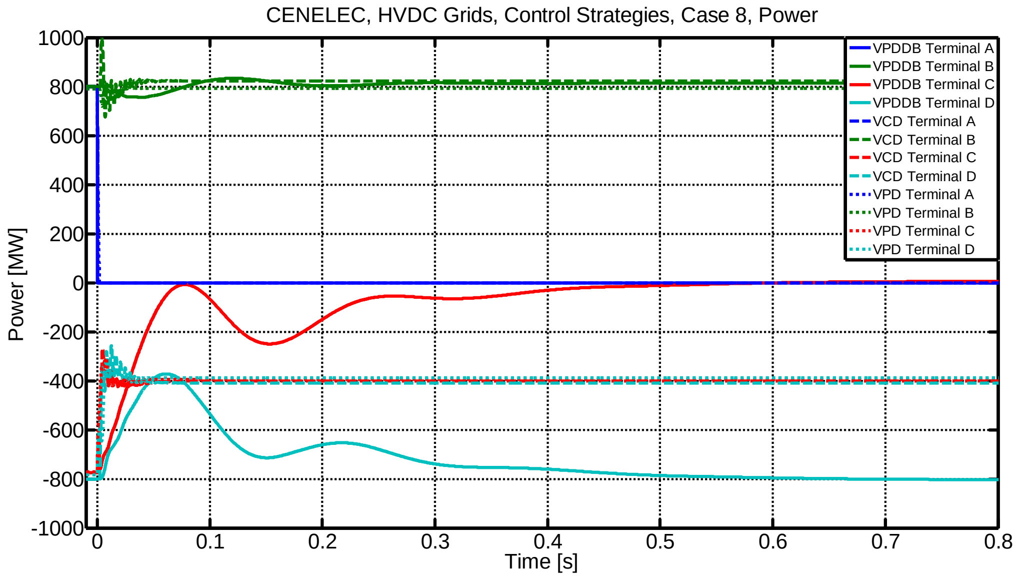
Operation of a combined HVAC and HVDC grid - Optimal Power Flow Control?



Operation of a combined HVAC and HVDC grid - Control Strategy?

- HVDC Terminal Control (CENELEC Study Group HVDC)
  - Voltage-power droop together with dead band
  - Voltage-current droop
  - Voltage-power droop





Conclusion

- Grid investments have to be inline with generation expansion
- Multi-terminal HVDC has several advantages
- Solution for optimal power flow possible
- Still a lot of open research questions

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Thank you for your attention
Questions

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