DOE/OE Transmission Reliability Program

Economics of High Voltage dc Networks

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Objective

- **DC lines have long been economically justified**
  - **They move power controllably**
  - **They move power long distances, stably**
  - **They can use cables**

- **Are DC *networks* justifiable on economic grounds?**
  - **Technically feasible (2015 report), add redundancy**
  - **Equipment is not fully utilized at all times**
  - **How to account for costs?**

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No universal answer

- **Whether a network is justifiable depends . . .**
  - **Project lifetime (load growth etc)**
  - **Politics (power trading)**
  - **Sustainability (generation mix)**
- **Some of these factors are (at best) guesswork**

- **We sought a trade-off method**

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Comparing Alternatives: Overview

- **ConOpsDoc**
  - Stability
  - Environmental
  - Power flows, losses (including effect on ac)
  - Ease of expansion
  - Communication needs

- **Compare like with like**

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Requirements

Level	Involves	Example	
1	Major stakeholders, owners, partners, sponsors	Build a transmission reinforcement mechanism for path ABCD that will ensure compliance with known NERC requirements on system reliability.	
1.5	Alternatives	DC transmission	AC transmission
2	"Application" requirements	The system shall be capable of steady state power transfer of 2 GW, with an overload capability of (TBR).	The system shall be capable of steady state power transfer of 2 GW, with an overload capability of (TBR).
2	"Application" requirements	The system shall have the ability to modulate the power flow in response to ac system conditions	Power system stabilizers shall have the ability to make positive damping in the event of any line outage
3	System; impacts several subsystems	Modulation controller shall have available information on voltage and power flow conditions throughout region encompassing path ABCD	PSSs shall respond regardless of initial loading conditions
4	Subsystem, or software program	Secure external communication system shall furnish controller information	No inter-area communication shall be needed
4	Subsystem, or software program	Security of communication system shall be reviewed annually	

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Factors

- Planning and Design
- Land
- Equipment
- Cash flow
- Ancillary services
- Damping (modulation)
- Black start
- Salvage value

- Combined? For simplicity, preliminary estimate

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Comment from Case Law

The Federal Power Act requires that the fee be 'just and reasonable,' 16 U.S.C. § 824d(a), and therefore at least roughly proportionate to the anticipated benefits to a utility of being able to use the grid.

On page 13 of the transcript* is the observation that "It's not enough for Illinois to point out that MISO's and FERC's attempt to match the costs and the benefits of the MVP program is crude; *if crude is all that is possible, it will have to suffice*.

* Illinois Commerce Commission *vs* Federal Energy Regulatory Commission

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The Literature

- Loehr “Take my grid, please”
- MISO Transmission Expansion Planning (MTEP) report 2014
- The WECC Interactive Transmission Project Portal
- Technical Limitations towards a SuperGrid – A European Perspective
- Transmission investment problems in Europe: Going beyond standard solutions
- Feasibility of DC Transmission Networks
- Barthold “tripole”
- McDonald point-to-point
- Li & McCalley overlay
- Kriegers Flak
- CIGRE WG B4
- Safety nets (new material)

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Loehr "Take my grid, please"

- **Complication**
  - **Retail access**
  - **Number or players**
  - **Complexity of procedures**
- **Culture shift**
  - **Cooperation and coordination becoming competition and confidentiality**
- **Priorities**
  - **Reliability gives way to price**

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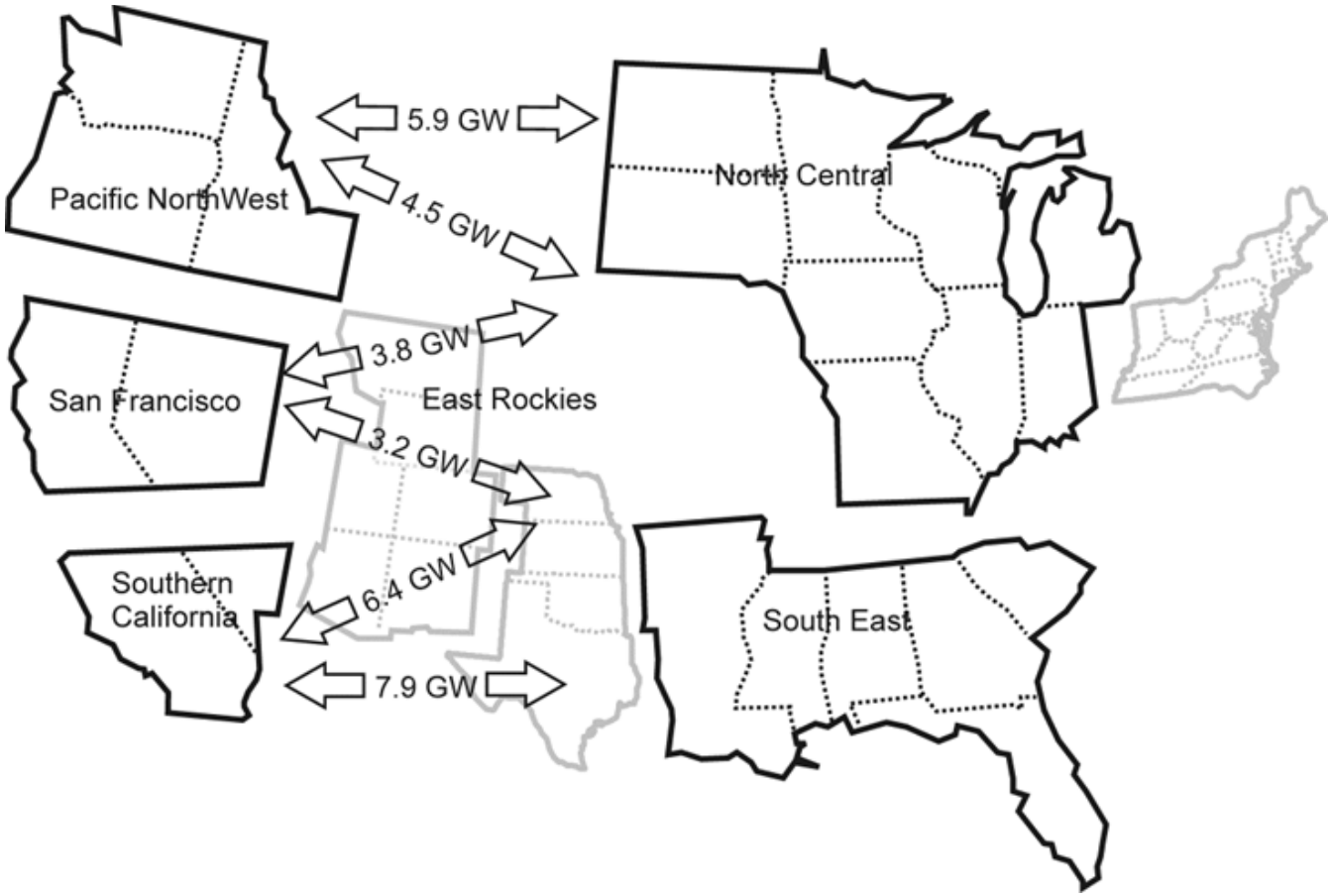
MISO Transmission Expansion Planning (MTEP) report 2014



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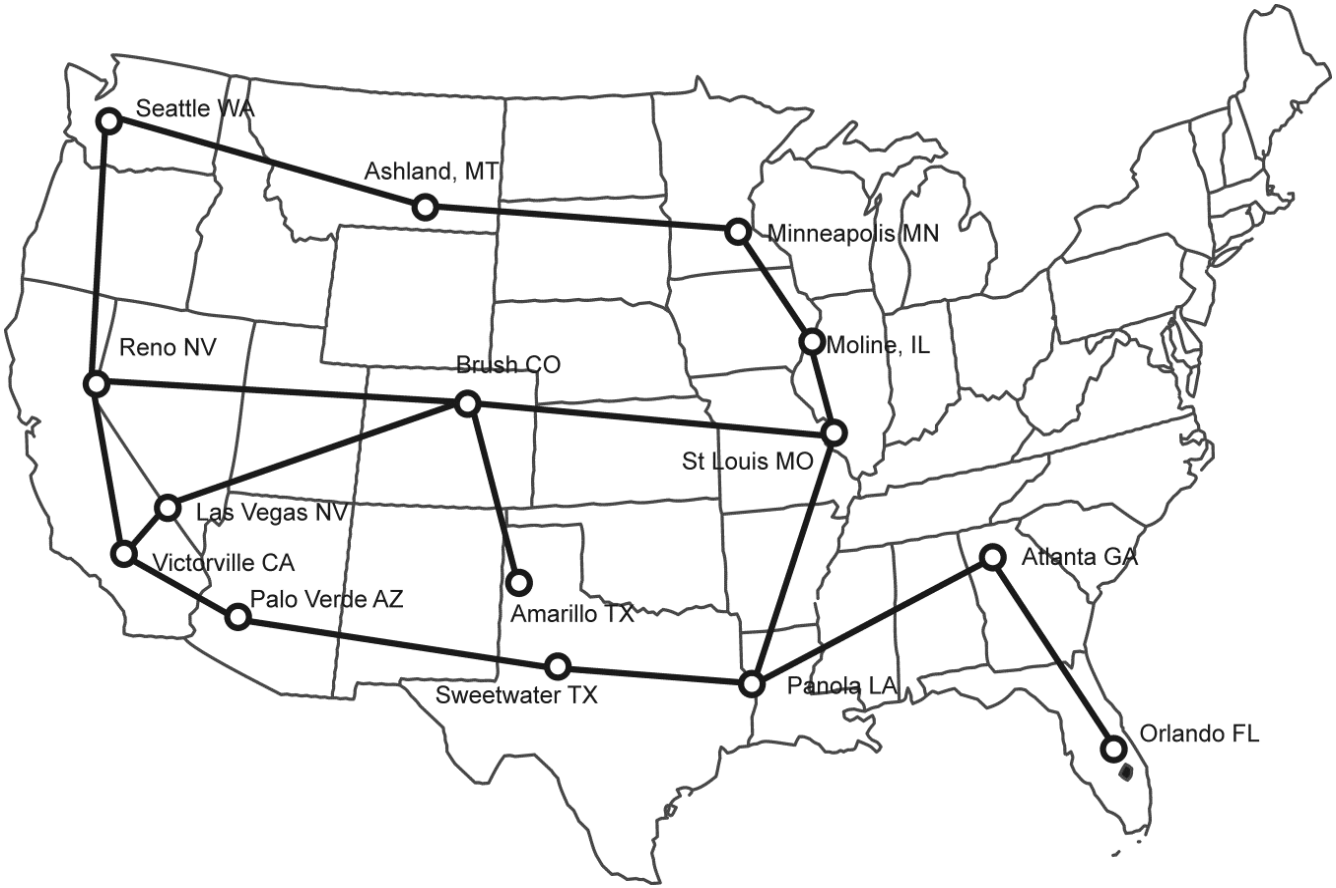

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MISO Transmission Expansion Planning (MTEP) report 2014

Spinning reserves

Interconnection	Frequency response spinning reserves		
	Actual	Based on HVdc network	Difference
MISO, SERC, FRCC	2900	1100	1800
WECC	2740	940	1800
ERCOT	2750	950	1800

WECC would get 45% of the benefits of the network, and MISO themselves 28%.

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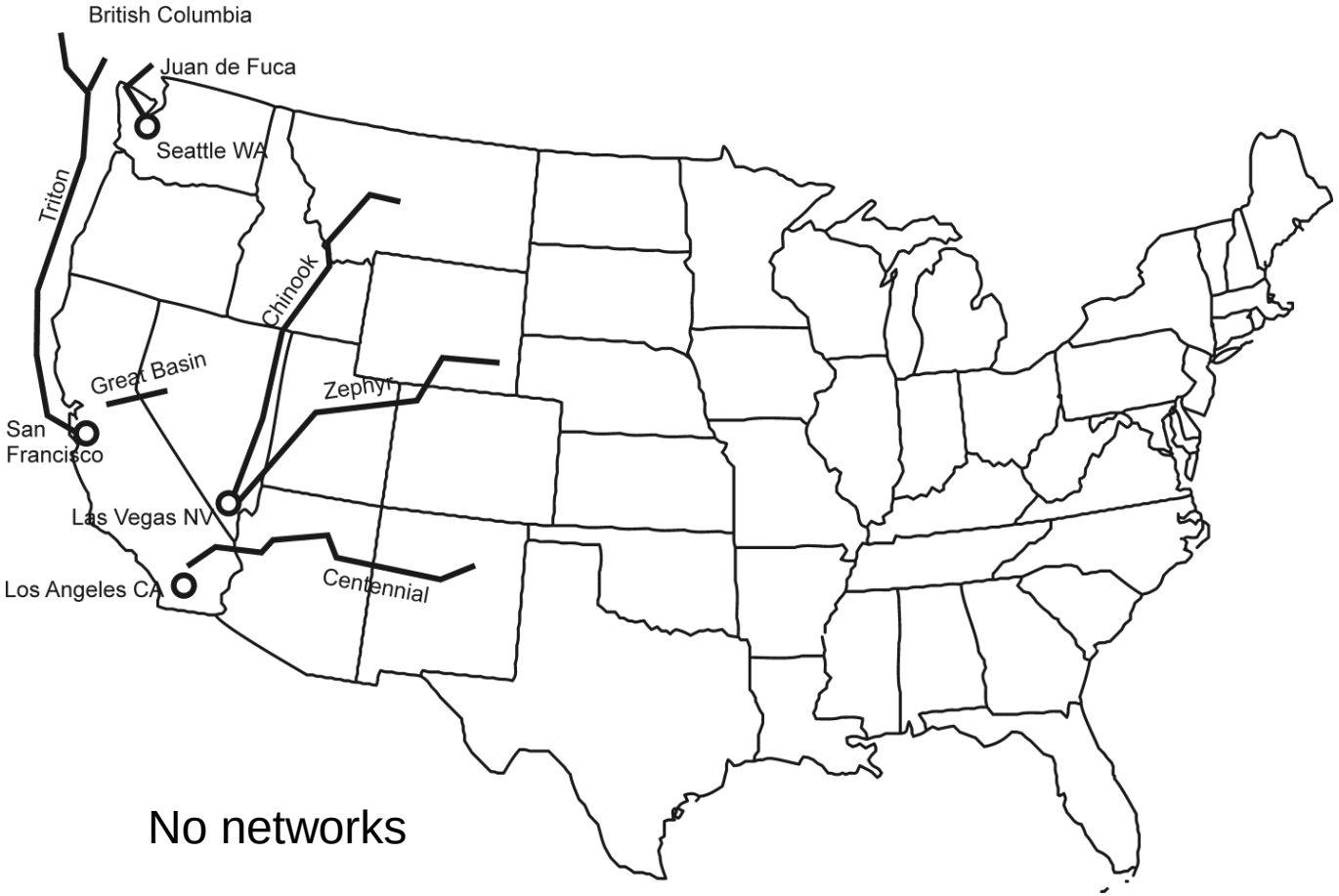
The WECC Interactive Transmission Project Portal



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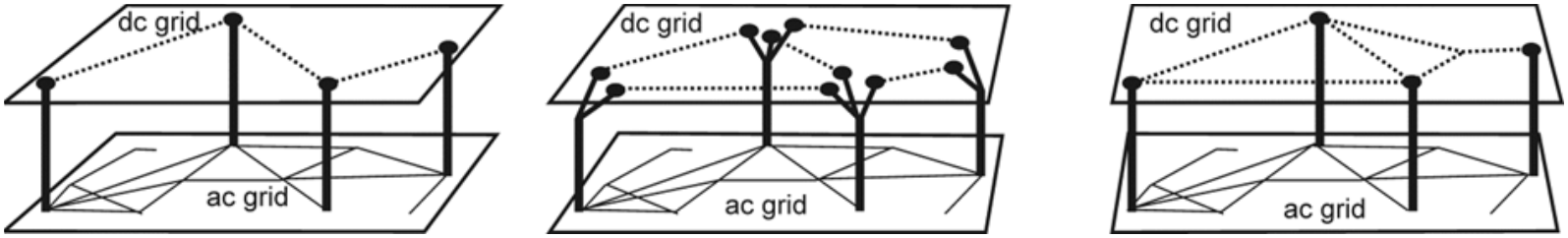
Technical Limitations towards a SuperGrid – A European Perspective

DC grid topologies



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Transmission investment problems in Europe: Going beyond standard solutions

Obstacle	Number of projects
Authorization procedures	12
Electric and Magnetic Fields	11
Environmental Issues	9
Grid Issues	9
Visual Impact	7
Densely populated area	7
Difficult terrain and Weather	4
Identification of cross-border point	3
Commercial problem	3
Dependency on other project(s)	2
No perception of supra-national or European perspective	2

Obstacles to cross-border OH lines in Europe

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Feasibility of DC Transmission Networks

- **Panel at ISGT-Europe (Dec 2011)**
- **Early 20th century drivers for ac now apply to HVdc**
- **But some challenges**
  - **Greater system complexity (and hence reliability problem)**
  - **Question of circuit breakers**
  - **Protection challenges – communication lag issue**
  - **Power flow redistribution**

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Barthold “tripole”

- Converting 3-phase ac to dc transmission, two wires on three
- Must not have ground current
- Uses “spare” conductor to relieve others, in rotation (few minutes)

AC Voltage	230 kV
DC Voltage	±200kV
Distance	200 km
Conductor	1,272 kcmil
Resistance	0.05 Ω/km
MVA max	514
MVA op	333
DC rating	345 Mw
Discount rate	2%

Years	30
Energy Value	$60/MWhr
Loss factor	0.5
Annual ac loss	121,431 MWhr
Annual dc loss	74,440 MWhr
Annual loss savings	46,991 MWhr
Annual Savings	$2.9M
NPV of savings	**$63M**
Credit/term	$94/kw

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McDonald point-to-point

- Large study
- Aimed at wind integration
- Geographic detail, renewables reality-based
- National rather than regional optimization
- Started by assuming power flows and ended by finding lines needed

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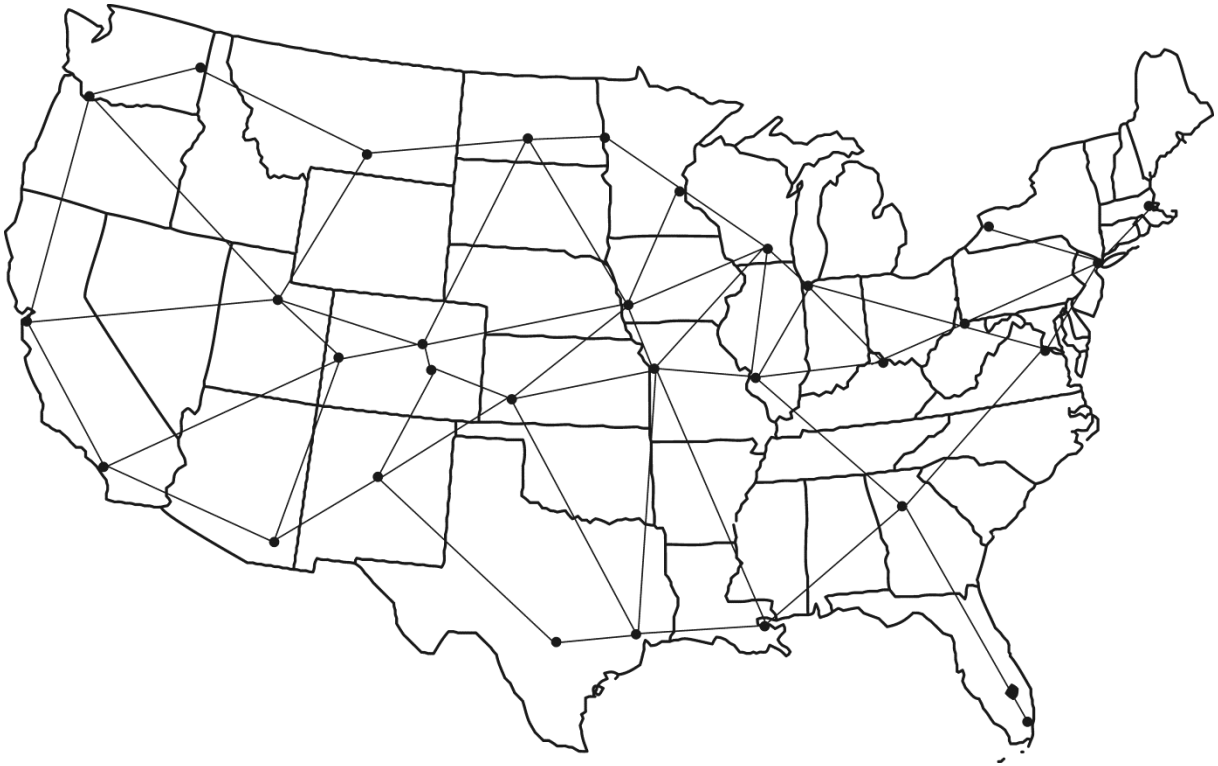
McDonald point-to-point



Savings $47Bn annually, 3 times cost of HVdc

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Li & McCalley overlay

- Considered sustainability
- Allowed for tapping but not real network
- Simulated transmission growth over time
- Started by assuming line locations, selecting some and rejecting others

- “significant benefits”

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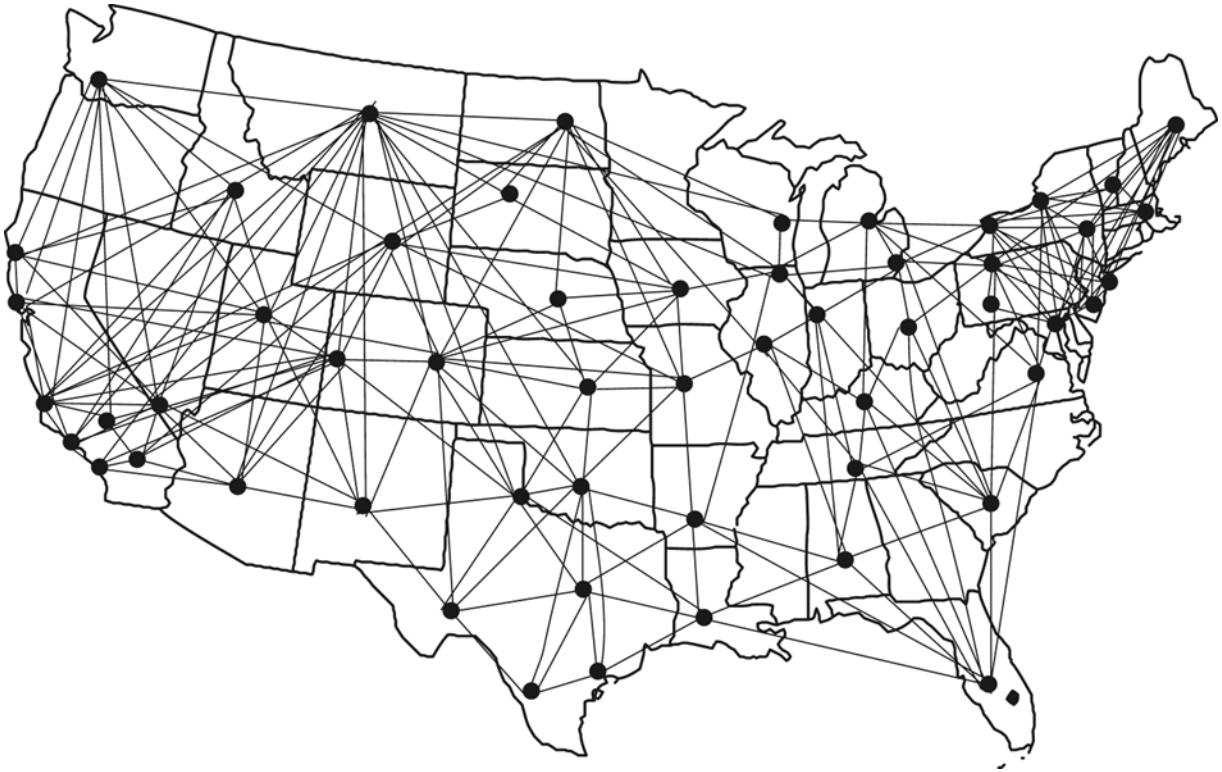
Li & McCalley overlay



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Kriegers Flak

- Considered 3 options in a trade-off study
  - 50Hertz
  - Svenska Kraftnät
  - Energinet/DK
- Base case ac and radial to wind area
- Combined Grid Solution higher cost but allows international trading

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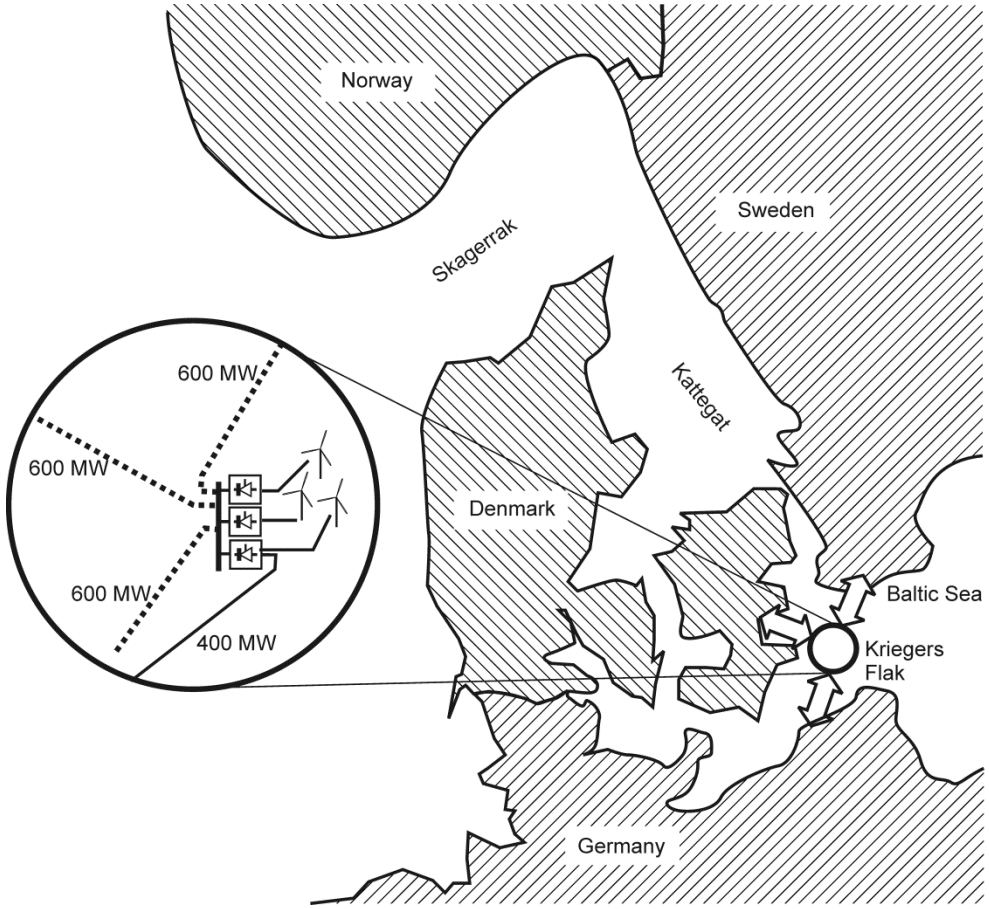
Kriegers Flak



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CIGRE WG B4

- Reviewed state of art
- Considered
  - Reactive support
  - Losses
  - Damping
  - Black start
  - OH and UG
  - Possibilities in Netherlands, Germany

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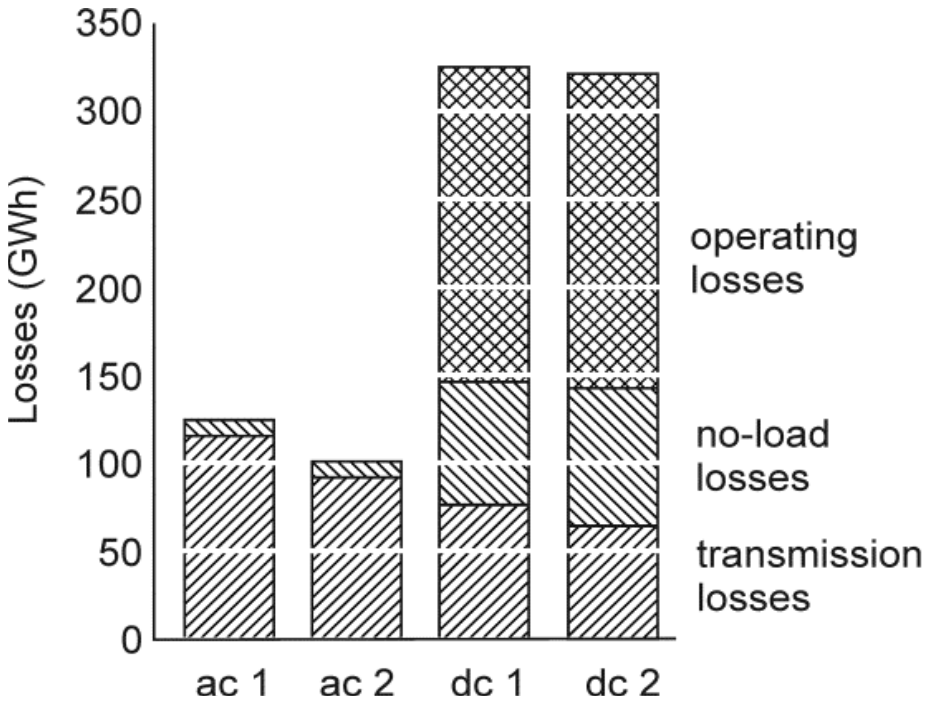
CIGRE WG B4



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CIGRE WG B4

Cash flow study

- Discount rate: 8%
- Power rating: 1500 MW
- Transmission distance: 1000 km
- Market price difference: 15 €/MWh
- Loss compensation price: 65 €/MWh
- Availability: 8300 h • Active power utilization 80 - 90%
- Reactive power utilization: max. ±650 – ±900 MVAr
- Black-start / Island-supply applicable: yes
- Asset lifetime: 40 years
- Period of consideration: 25 years then retrofit

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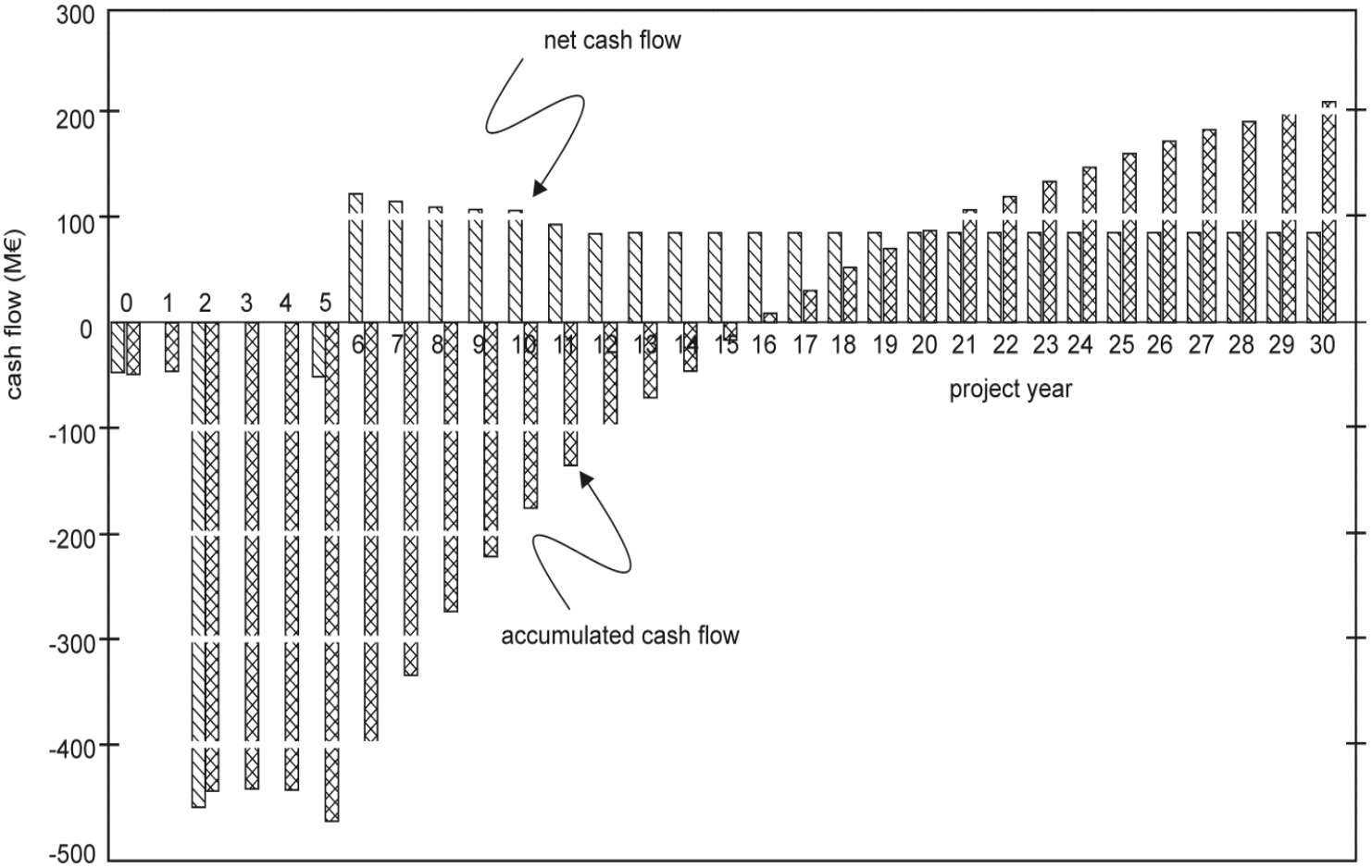
CIGRE WG B4



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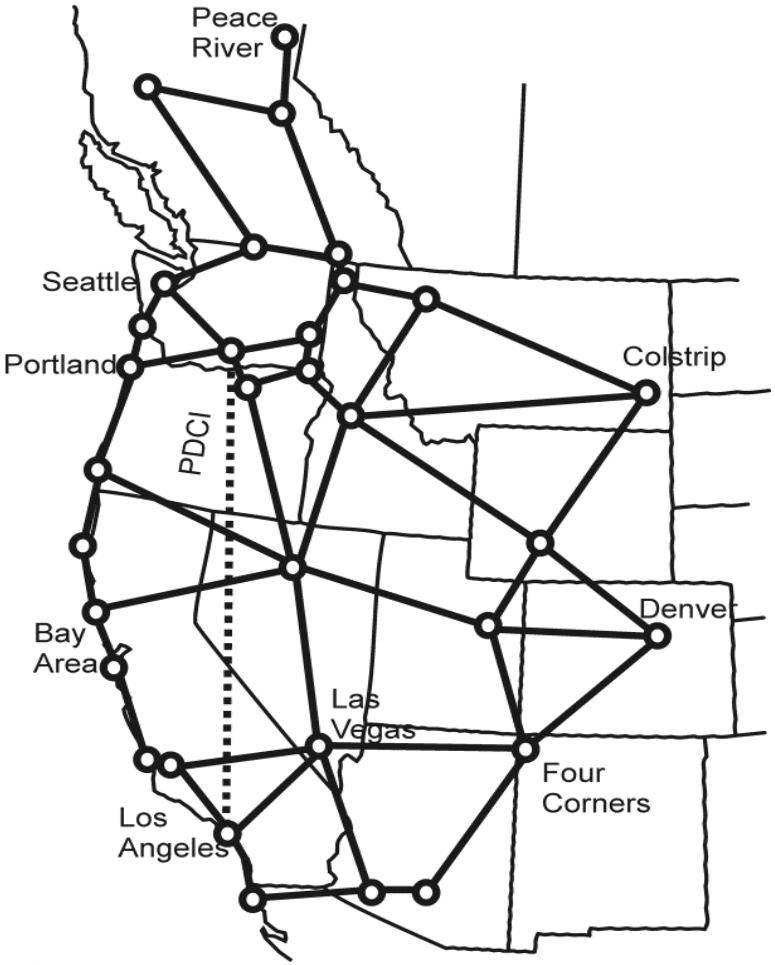
Safety nets (new material)



- Maintain stability
- Generator based, not load
- No large lines
- Similar in Taiwan, smaller

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Conclusions

- Do like CIGRE
- But include specific factors
- Get the spreadsheet right! Make it interactive

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Appendices on “interesting HVdc schemes”

- PDCI
- North-East India to Agra
- Russian HVdc

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Question times

ВВОД В ЭКСПЛУАТАЦИЮ ЛЕКТРОПЕРЕДАЧИ` ПОСТОЯННОГО ТОКА 1500 КВ ЭКИБАСТУЗ-ЦЕНТР ПОЗВОЛИТ БЕЗ ДОПОЛНИТЕЛЬНОГО СОЗДАНИЯ В ЕВРОПЕЙСКОЙ ЧАСТИ СССР СОБСТВЕННЫХ МАНЕВРЕННЫХ ЭНЕРГОМОЩНОСТЕЙ ПЕРЕДАТЬ В ЭТОТ РАЙОН ИЗ СИБИРИ ДО 4 млн.кВт ИСПОЛЬЗУЕЮЙ МОШНОСТИ ГЭС С ВОЗВРАТОМ В НОЧНЫЕ ЧАСЫ 5 млн.кВт В ОЭС СИБИРИ ЗА СЧЕТ ИСПОЛЬЗОВАНИЯ БАЗИСНОЙ МОШНОСТИ АЭС.

Approximate translation: Commissioning the 1500 kV dc line from Ekibastuz to Center will allow without additional creation of power infrastructure in the European part of the USSR to transmit 4GW of maneuverable [hydro] power from Siberia and return 5 GW [from nuclear generation] at night

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