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?
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
Comparing Alternatives: Overview

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

- **Compare like with like**
## Requirements

<table>
<thead>
<tr>
<th>Level</th>
<th>Involves</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Major stakeholders, owners, partners, sponsors</td>
<td>Build a transmission reinforcement mechanism for path ABCD that will ensure compliance with known NERC requirements on system reliability.</td>
</tr>
<tr>
<td>1.5</td>
<td>Alternatives</td>
<td>DC transmission</td>
</tr>
<tr>
<td>2</td>
<td>&quot;Application&quot; requirements</td>
<td>The system shall be capable of steady state power transfer of 2 GW, with an overload capability of (TBR).</td>
</tr>
<tr>
<td>2</td>
<td>&quot;Application&quot; requirements</td>
<td>The system shall have the ability to modulate the power flow in response to ac system conditions</td>
</tr>
<tr>
<td>3</td>
<td>System; impacts several subsystems</td>
<td>Modulation controller shall have available information on voltage and power flow conditions throughout region encompassing path ABCD</td>
</tr>
<tr>
<td>4</td>
<td>Subsystem, or software program</td>
<td>Secure external communication system shall furnish controller information</td>
</tr>
<tr>
<td>4</td>
<td>Subsystem, or software program</td>
<td>Security of communication system shall be reviewed annually</td>
</tr>
</tbody>
</table>
Factors

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

- Combined? For simplicity, preliminary estimate
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
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)
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
MISO Transmission Expansion Planning (MTEP) report 2014
MISO Transmission Expansion Planning (MTEP) report 2014
### Spinning reserves

<table>
<thead>
<tr>
<th>Interconnection</th>
<th>Frequency response spinning reserves</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Based on HVdc network</td>
<td>Difference</td>
<td></td>
</tr>
<tr>
<td>MISO, SERC, FRCC</td>
<td>2900</td>
<td>1100</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>WECC</td>
<td>2740</td>
<td>940</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>ERCOT</td>
<td>2750</td>
<td>950</td>
<td>1800</td>
<td></td>
</tr>
</tbody>
</table>

WECC would get 45% of the benefits of the network, and MISO themselves 28%.
The WECC Interactive Transmission Project Portal

No networks
Technical Limitations towards a SuperGrid – A European Perspective

DC grid topologies
Transmission investment problems in Europe: Going beyond standard solutions

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

Obstacles to cross-border OH lines in Europe
Feasibility of DC Transmission Networks

• Panel at ISGT-Europe (Dec 2011)

• Early 20\textsuperscript{th} 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
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)

<table>
<thead>
<tr>
<th></th>
<th>AS Voltage</th>
<th>230 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Voltage</td>
<td>±200kV</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>200 km</td>
<td></td>
</tr>
<tr>
<td>Conductor</td>
<td>1,272 kcmil</td>
<td></td>
</tr>
<tr>
<td>Resistance</td>
<td>0.05 Ω/km</td>
<td></td>
</tr>
<tr>
<td>MVA max</td>
<td>514</td>
<td></td>
</tr>
<tr>
<td>MVA op</td>
<td>333</td>
<td></td>
</tr>
<tr>
<td>DC rating</td>
<td>345 Mw</td>
<td></td>
</tr>
<tr>
<td>Discount rate</td>
<td>2%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Years</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Value</td>
<td>$60/MWhr</td>
<td></td>
</tr>
<tr>
<td>Loss factor</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Annual ac loss</td>
<td>121,431 MWhr</td>
<td></td>
</tr>
<tr>
<td>Annual dc loss</td>
<td>74,440 MWhr</td>
<td></td>
</tr>
<tr>
<td>Annual loss savings</td>
<td>46,991 MWhr</td>
<td></td>
</tr>
<tr>
<td>Annual Savings</td>
<td>$2.9M</td>
<td></td>
</tr>
<tr>
<td>NPV of Savings</td>
<td>$63M</td>
<td></td>
</tr>
<tr>
<td>Credit/term</td>
<td>$94/kw</td>
<td></td>
</tr>
</tbody>
</table>
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
McDonald point-to-point

Savings $47Bn annually, 3 times cost of HVdc
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”
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
Kriegers Flak
CIGRE WG B4

- Reviewed state of art
- Considered
  - Reactive support
  - Losses
  - Damping
  - Black start
  - OH and UG
  - Possibilities in Netherlands, Germany
CIGRE WG B4

Losses (GWh)

- Operating losses
- No-load losses
- Transmission losses

ac 1, ac 2, dc 1, dc 2
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
Safety nets (new material)

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

- Do like CIGRE
- But include specific factors
- Get the spreadsheet right! Make it interactive
Appendices on “interesting HVdc schemes”

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