High Wind Penetrations: Ancillary Services and Transmission

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Outline

1. Wind and regulation
   • The problem
   • Benefits of storage

2. Wind and transmission
   • Interregional transmission (IT)
   • Resource to backbone (R2B) for Iowa
   • Superconducting generators

3. Conclusions
Wind increases regulation requirements

Variation in wind output increases the net load ramp rate (in this period from 4,052 MW/hour to 4,560 MW/hour)

Uncertainty in wind output increases uncertainty in net load to be met with conventional generators


Note: This figure uses load data from the Electric Reliability Council of Texas (ERCOT) in 2005 along with 15 GW of spatially diverse simulated wind data from the same year.
Providing regulation services

• A market commodity (along with energy)
• How to provide it:
  • Combustion turbines
  • Demand-side control
  • Wind plant control
  • Storage: bulk (CAES, PHS) and short-term (flywheel, battery)
• Bulk storage is attractive because it also provides other services
How does storage assist system and make money?

<table>
<thead>
<tr>
<th>Assist system?</th>
<th>Make money?</th>
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</thead>
<tbody>
<tr>
<td>Load leveling</td>
<td>Energy arbitrage</td>
</tr>
<tr>
<td>Responding to variability</td>
<td>AS: Regulation</td>
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<tr>
<td>Providing contingency backup</td>
<td>AS: reserves</td>
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<td>Providing peak capacity</td>
<td>Capacity market</td>
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<td>Congestion management</td>
<td>Congestion rents</td>
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<td>Offsetting transmission</td>
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<td>Reducing thermal cycling</td>
<td></td>
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<td>Improving freq performance</td>
<td></td>
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<tr>
<td>Providing voltage regulation</td>
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</table>
Storage classification – by operational modes

4-Quadrant
CAES, PHS, large capacity batteries
- Regulation-Up
  - Discharge Increase
  - Charge Decrease
- Regulation-Down
  - Discharge Decrease
  - Charge Increase

2-Quadrant
Flywheel, SMES, small capacity batteries
- Regulation-Up
  - Discharge Increase
- Regulation-Down
  - Charge Decrease
Conventional generator
- Regulation-Up
  - Discharge Increase
- Regulation-Down
  - Charge Decrease

Short-term storage has little energy arbitrage potential; therefore no reason to be charging while providing RU or discharging while providing RD. That is, it is a regulation-provider only.
Energy arbitrage

Simulated a 50 MW CAES in a 3405 MW system (2490 MW of peak load)

ENERGY-ARBITRAGE: Charging during low-LMP off-peak periods and discharging during high-LMP peak-demand periods

CAES is charged during low LMPs (≤15$/MWh) and discharged during high LMPs (≥28.03$/MWh).
Cross-arbitrage

CROSS-ARBITRAGE: Charges from the regulation market and discharges into the energy market or charges from the energy market and discharges into the regulation market

The amount of down-regulation is more than up-regulation, charging up the reservoir for energy dispatch during high LMP periods

Without AS, 2-day revenue from energy market is $3.54K.

With AS, 2-day revenue from energy market is $11.28K
Effects of different wind penetration levels
100 MW CAES for wind capacity penetrations of 22, 40, 50, 60%
## Payback analysis

<table>
<thead>
<tr>
<th>Attributes</th>
<th>CAES 50MW</th>
<th>CAES 100MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Penetration</td>
<td>WP 22</td>
<td>WP 22</td>
</tr>
<tr>
<td>Energy Discharge (MWh)</td>
<td>386.45</td>
<td>452.06</td>
</tr>
<tr>
<td>Up-Reg/Down-Reg (MW-hr)</td>
<td>288/682</td>
<td>138/682</td>
</tr>
<tr>
<td>Spin/Non-Spin (MW-hr)</td>
<td>0/0</td>
<td>67/0</td>
</tr>
<tr>
<td>Yearly Fuel Cost (M$)</td>
<td>1.23</td>
<td>1.35</td>
</tr>
<tr>
<td>Yearly Fixed O&amp;M Cost (M$)</td>
<td>1.63</td>
<td>3.26</td>
</tr>
<tr>
<td>Investment Cost (M$)</td>
<td>25.5</td>
<td>51</td>
</tr>
<tr>
<td>Ancillary Revenue (K$)</td>
<td>16.97</td>
<td>11.81</td>
</tr>
<tr>
<td>Energy Revenue (K$)</td>
<td>8.06</td>
<td>11.28</td>
</tr>
<tr>
<td>Total Yearly Revenue (M$)</td>
<td>4.55</td>
<td>4.20</td>
</tr>
<tr>
<td>Yearly Profit (M$)</td>
<td>1.70</td>
<td>-0.413</td>
</tr>
<tr>
<td>Payback (years)</td>
<td>15.02</td>
<td>-</td>
</tr>
</tbody>
</table>

- Sensitivity studies show that storage economics significantly benefit from inclusion of cycling costs in AS offers: CAES 100 MW @ WP 60% PB ➔ 9 to 5 years
Why interregional transmission (IT)?

High-capacity interregional transmission is motivated by high renewable penetration because...

• Location dependence.
• Renewable energy can be moved only by electric transmission.
• Transmission costs comprise a relatively small percent of long-term power system cost.

⇒ Under high-renewable futures, total cost decreases by building least-cost generation and moving it to load centers.
Used multi-period (40-yr) co-optimization to design transmission for 62 node national model

- Accurately represented existing gen; new gen chosen from 15 types.
- Existing transmission modeled between nodes.
- Transmission technologies included ±600, 800kV DC; 500, 765kV AC; HVDC required for transmission between EI, WECC, and ERCOT.
- Specified demand and generation technology percentages; program identified generation locations & transmission to minimize total cost.
Results - High Inland-Wind Scenario
Cost: with & without IT

For high-renewable generation portfolio, interregional transmission investment lowers cost and lowers emissions.

Other benefits:
- Reduced emissions
- Enhanced resilience of energy prices to large-scale events;
- More flexible to different futures.
Resource Nationalism?

“One problem,” he said, is “resource nationalism,” in which individual states want to use local resources, whether they are coal or yet-to-be-built offshore wind, rather than importing from neighbors in a way that could be more economical.

James Hoecker,
FERC Commissioner 1993-2001,
FERC Chair 1997-2001

Impact of Transmission Expansion on Average LMPs for High Inland Wind Scenario

Legend:
-0.52875: Energy Price will increase by 0.52875 M$/GW
1.3531: Energy Price will decrease by 1.3531 M$/GW
Impact of Generation Expansion on Job Creation for High Inland-Wind Scenario

Legend:

ERC-W
401300: Total number of job opportunity created on the node
R2B Transmission Design in Iowa for 20 GW Wind Penetration
High Capacity Transmission for Iowa

2010 SmartTransmission Study

2011 MISO RGOS Study

2008 Joint Coordinated System Plan

2010 Green Power Express

2013 Rock Island Clean Line
GIS-based wind farm site potential
Feasibility: land cvr, cities/towns, protected, FAA, exstng WF
Feasible sites > 21 mi²; Sufficient wind>7m/s at 80m
Each square is 5x5 miles; 8MW/mi² (200MW/square)
927 squares are PINK (sufficient wind and feasible site)
Iowa Transmission System with New Backbone

- Derived from public data:
  - IUB map, FERC filings, utility websites, EIA, MTEP
- Existing system model includes:
  - transmission >100kV
  - 319 transmission lines,
  - 204 nodes, 99 loads,
  - 81 generators, 40 wind farms
- 5 bordering states:
  - gen/load represented at single node
- Backbone design:
  - utilized MTEP-2011 plans + 765kV loop to connect wind intense areas with load centers in Iowa & eastward.
Wind Farm Site Identification

Select sites to satisfy target GW level while minimizing 
\{\text{cost of turbines} + \text{cost of transmission}\} per MWhr.

<table>
<thead>
<tr>
<th>765kV Overlay</th>
<th>10GW</th>
<th>20GW</th>
<th>30GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Capacity (MW)</td>
<td>4954</td>
<td>14956</td>
<td>24960</td>
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<tr>
<td>New Wind Farms (1 windfarm = 200MW square)</td>
<td>27</td>
<td>79</td>
<td>133</td>
</tr>
<tr>
<td>CF of New Wind</td>
<td>0.3824</td>
<td>0.3751</td>
<td>0.3708</td>
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<tr>
<td>Mean Distance (mi)</td>
<td>4.33</td>
<td>6.52</td>
<td>8.68</td>
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</table>
R2B Transmission Design Results

Transmission designs for each cluster minimize investment costs while satisfying N-1 reliability constraints (20 GW future).
## R2B Transmission Design Results

### 765kV Overlay 20GW Scenario

<table>
<thead>
<tr>
<th>Wind Farms Paths Ccts</th>
<th>161 Single 161 High 345 Single 161 Dble 345 Dble</th>
<th>ROW Miles</th>
<th>Circuit Miles</th>
<th>Cost $M</th>
<th>cct miles / Wind Farm $M/ct/mi</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10 4 0 3 2</td>
<td>109.1</td>
<td>133.6</td>
<td>120.3</td>
<td>8.91 0.90</td>
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<tr>
<td>B</td>
<td>6 0 0 6 1</td>
<td>61.4</td>
<td>92.9</td>
<td>75</td>
<td>8.45 0.81</td>
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<tr>
<td>C</td>
<td>10 1 0 6 1</td>
<td>93.5</td>
<td>127.3</td>
<td>101.7</td>
<td>9.79 0.80</td>
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<tr>
<td>D</td>
<td>9 0 0 2 1</td>
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<td>80.2</td>
<td>68</td>
<td>8.91 0.85</td>
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<tr>
<td>E</td>
<td>17 0 0 0 0</td>
<td>120.3</td>
<td>120.3</td>
<td>96.2</td>
<td>10.94 0.80</td>
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<tr>
<td>F</td>
<td>3 0 0 3 0</td>
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<td>77.2</td>
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<td>15.44 0.76</td>
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<tr>
<td>G</td>
<td>4 2 0 1 1</td>
<td>49.3</td>
<td>62.4</td>
<td>59.1</td>
<td>10.40 0.95</td>
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<tr>
<td>H</td>
<td>3 0 0 4 0</td>
<td>42.9</td>
<td>64.8</td>
<td>49.7</td>
<td>10.80 0.77</td>
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<tr>
<td>All</td>
<td>62 7 0 25 6</td>
<td>590.7</td>
<td>758.7</td>
<td>628.8</td>
<td>9.98 0.83</td>
</tr>
</tbody>
</table>

### Option #1

<table>
<thead>
<tr>
<th>Voltage (kV)</th>
<th>Cost ($M/mi)</th>
<th>Rating (MW/cct)</th>
<th>PSIL (MVA)</th>
<th>X (p.u./mi)</th>
<th>Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>161</td>
<td>0.8</td>
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<tr>
<td>3</td>
<td>2.3</td>
<td>1100</td>
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<tr>
<td>4</td>
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<td>273</td>
<td>79</td>
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<td>5</td>
<td>2.8</td>
<td>1100</td>
<td>403</td>
<td>0.00052</td>
<td>2</td>
</tr>
</tbody>
</table>
Concluding Comments

1. Storage
   • Bulk storage is expensive but its flexibility enables it to provide system services and obtain revenues via arbitrage and cross-arbitrage; even more attractive if thermals include cycling cost
   • Short-term storage participates only in AS but is cheap and can therefore be very economic
   • All storage looks better as wind/solar increase; but so does demand-side & wind control, so need to compare.

2. High-capacity interregional transmission
   • Lowers cost and emissions
   • Improves resilience (ability to min/recover from extreme events)
   • Improves flexibility (ability to adapt to future scenarios)

3. R2B transmission
   • Iowa wind penetration is limited by transmission
   • Transmission design for high wind: incremental vs systematic?
   • Increased wind turbine capacity will increase energy density...
High Temperature Superconductors (HTS) for Inland Wind Turbines

- HTS operates at ~40°K (-233°C)
- No R→High Current→High Flux
- Raise turbine capacity from ~3MW to ~10MW (must also raise turbine height, an issue)
- Raise windplant capacity from 200MW/25mi² to 500MW/25mi²
- Changes our Iowa R2B study, with 76 new windfarms, from 20GW to 43GW