Electric Power Grid of the Future

CIGRE Next Generation Network
March 4, 2020

Rob Gramlich
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Grid History and Future
with high penetration renewables

1. Traditional vertical industry structure
2. Need for regionalization
3. Need for a robust macro grid
4. Need for efficient transmission utilization
5. Need for large regional power markets
6. Reliability considerations
7. Hybrid resources
Traditional vertically integrated utility structure
Traditional vertical utilities
Regionalization with RTOs and ISOs
RTO Characteristics and Functions

Characteristics:
1. Independence
2. Scope and regional configuration
3. Operational authority

Functions:
1. Administer and design tariffs
2. Manage congestion
3. Solve the parallel path flow problem
4. Manage and provide ancillary services
5. Maintain OASIS and post the transmission capability
6. Perform market monitoring
7. Plan and manage transmission system expansion
8. Handle interregional coordination.
Wholesale Competition Structure

Transmission and Renewable Energy

• Best wind and solar far from load

NREL Wind (left) and Solar (right) Resource Maps

Transmission in other countries: China case
Europe Renewables and Transmission

# US Transmission Congestion Costs Rising (Again)

Transmission Congestion Costs ($ millions) for RTOs from 2016-2018

<table>
<thead>
<tr>
<th>RTO</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERCOT</td>
<td>497</td>
<td>976</td>
<td>1,260</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>38.9</td>
<td>41.4</td>
<td>64.5</td>
</tr>
<tr>
<td>MISO</td>
<td>1,400</td>
<td>1,500</td>
<td>1,400</td>
</tr>
<tr>
<td>NYISO</td>
<td>529</td>
<td>481</td>
<td>596</td>
</tr>
<tr>
<td>PJM</td>
<td>1,023.7</td>
<td>697.6</td>
<td>1,310</td>
</tr>
<tr>
<td>SPP</td>
<td>273.7</td>
<td>405.3</td>
<td>380.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,762.3</strong></td>
<td><strong>4,101.3</strong></td>
<td><strong>5,011.3</strong></td>
</tr>
</tbody>
</table>
First, Use the Existing Grid More Efficiently

• Power Flow Control
  • Push and pull power, modular, scalable, movable

• Dynamic Line Ratings
  • Adjust path rating based on ambient conditions, allows capacity forecasting

• Topology Optimization
  • Software to optimize transmission assets, eg circuit breakers

• Storage as Transmission

➤ Re-set incentives on transmission owners
Recent Large-Scale Expansions

- MISO MVP, SPP priority projects, ERCOT CREZ
- 3:1 Benefit-Cost ratios
- Winning formula:
  - Pro-active multi-benefit planning
  - Broad, beneficiary pays allocation
Transmission Enabled ½ of US Wind Capacity

~105 GW installed in US

<table>
<thead>
<tr>
<th>Transmission plan</th>
<th>Wind Capacity Enabled (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tehachapi</td>
<td>4.5</td>
</tr>
<tr>
<td>Texas CREZ</td>
<td>14.5</td>
</tr>
<tr>
<td>MISO MVP</td>
<td>14</td>
</tr>
<tr>
<td>SPP Priority Projects, Balanced Portfolio</td>
<td>6</td>
</tr>
<tr>
<td>CO+ME+NV+PAC+BPA</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
</tr>
</tbody>
</table>
Transmission Barrier 1: Permitting

- State by state review
- States impacting other states, national interest not being considered
Transmission Barrier 2: Narrow planning

- Almost no inter-regional plans have been produced
- Planning by RTOs has been ground-up rather than comprehensive
- Planning has not been pro-active to consider known generation development in resource areas
- Planning benefits have been compartmentalized: economic/reliability/resilience/generator interconnection

→ Broad regional and inter-regional multi-purpose planning
Transmission Barrier 3: Funding

• FERC generator interconnection policy allowed “participant funding”
  • Even when many generators are connecting in the same area
• Not all benefits considered

➙ Broad cost allocation
  • Consider all benefits
  • As they may change over time
  • FERC assign costs to all beneficiaries

➙ Investment Tax Credit
Market Design for an Evolving Resource Mix

• **Flexible**
  - Fast (e.g., 5 minute) dispatch, price based on value
  - Close to real time commitments and dispatch

• **Fair**
  - Technology neutral—pay for DELIVERED SERVICES, not ATTRIBUTES
  - Small building blocks

• **Far**
  - Large geographic areas with seamless trading

• **Free**
  - Bilateral contracts uninhibited
  - Full demand side participation, all flavors

# Wholesale Price Effects of 40-50% Wind & Solar

(Wind: 30% wind & 10+% solar | Balanced: 20% wind & 20% solar | Solar: 30% solar & 10+% wind)

<table>
<thead>
<tr>
<th>Impacts in 2030</th>
<th>Southwest Power Pool</th>
<th>NYISO (New York)</th>
<th>CAISO (California)</th>
<th>ERCOT (Texas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016: 18% wind &amp; 0% solar</td>
<td>2016: 7% wind &amp; 14% solar</td>
<td>2016: 16% wind &amp; 1% solar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>Balanced</td>
<td>Solar</td>
<td>Wind</td>
<td>Balanced</td>
</tr>
<tr>
<td>Lower Average Prices [$/MWh]</td>
<td>-19%</td>
<td>-21%</td>
<td>-27%</td>
<td>-37%</td>
</tr>
<tr>
<td>More Hours &lt;$5/MWh</td>
<td>6%</td>
<td>8%</td>
<td>13%</td>
<td>2%</td>
</tr>
<tr>
<td>Changes in Diurnal Price Profile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>red baseline shows 2016 wind &amp; solar shares</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More Price Variability</td>
<td>1.8x</td>
<td>2.1x</td>
<td>2.5x</td>
<td>2.1x</td>
</tr>
<tr>
<td>Higher AS Prices Regulation Down</td>
<td>5x</td>
<td>6x</td>
<td>9x</td>
<td>2x</td>
</tr>
<tr>
<td>Change in Timing of Top Net-Load Hours</td>
<td>Shift from 4pm to 7pm</td>
<td>Shift from 3pm to 5-7pm</td>
<td>No further shift 7pm</td>
<td>Shift from 3pm to 6-8pm</td>
</tr>
</tbody>
</table>

Source: LBNL
Best Market Structure for Low Cost De-Carbonization

• **Environmental regulators** internalize externalities
• **RTO/ISO** balances power system and administers short term spot markets
  • Procures energy and reliability services based on engineering definitions
  • Also plans transmission infrastructure for reliability and efficiency given future resource mix, recovers cost in regional tariff
• **Retail suppliers** competitively procure power (hedge) with PPAs to serve load
• **State PUCs** oversee hedging for some or all customers
  • ensure retail suppliers are credit-worthy buyers of wholesale power
  • Level playing field between retailers and provider of last resort
• **Utilities** build, own, and operate monopoly T&D (not G) with regulated rates
• **Independent Power Producers** build and own generation to sell electricity products to retail suppliers/wholesale buyers
• **Financial participants** provide risk management products
Reliability Efforts with Generation being considered by NERC and RTOs

• Common mode failures affecting multiple generators that are getting credit for having uncorrelated outages

• Peak energy supply in Northeast/Midwest winter Polar Vortices
  • If gas and transmission import constraints

• Ride-through capability and settings on inverter-based technologies

• Stability in weak areas of the grid

• Inertia/Fast Frequency Response adequacy with declining amounts of synchronous generation
## Reliability Services of Generation Sources

<table>
<thead>
<tr>
<th></th>
<th>Inverter-Based</th>
<th>Synchronous</th>
<th>Demand Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wind</td>
<td>Solar PV</td>
<td>Storage/Battery</td>
</tr>
<tr>
<td>Disturbance ride-through</td>
<td></td>
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<tr>
<td>Reactive and Voltage Support</td>
<td></td>
<td></td>
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<tr>
<td>Slow and arrest frequency decline (arresting period)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Stabilize frequency (rebound period)</td>
<td></td>
<td></td>
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<tr>
<td>Restore frequency (recovery period)</td>
<td></td>
<td></td>
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<tr>
<td>Frequency Regulation (AGC)</td>
<td></td>
<td></td>
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<tr>
<td>Dispatchability/Flexibility</td>
<td></td>
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</tbody>
</table>
Physical Balancing With High Renewables: Fuel Security in ISO-NE

More reliable

Less reliable

High Renewable Scenarios
New Development: Hybrid Resources

- Interconnection
- Operational protocols
- Capacity value

Enabling Versatility: Allowing Hybrid Resources to Deliver Their Full Value to Customers

Rob Gramlich and Michael Goggin, Grid Strategies LLC
Jason Burwen, Energy Storage Association

September 2019

www.gridstrategiesllc.com
Hybrid Resource Efficiencies

- Solar PV clipping with and without storage
WHOLESALE ELECTRICITY MARKET DESIGN FOR RAPID DECARBONIZATION: A DECENTRALIZED MARKETS APPROACH

BY ROB GRAMLICH AND MICHAEL HOGAN • JUNE 2019

"What wholesale market design would provide the best framework for integrating reliably and at least cost the new, clean resources that will be needed to decarbonize the power system?" This common question includes what model best generates clean resources from wind and solar, what role the wholesale market should play in enabling new "smart" resources at the distribution/local level, the question also includes both market structure (which entities perform which functions) and market design (how are the trading, bidding, and price-setting rules). For pace and scale of new investment in clean resources will be determined in part by how they are incentivized, by environmental regulations or regulations, public policy instruments, including zero-carbon portfolio standards or carbon cap-and-trade, should be designed to address the market for carbon or its direct mitigation rather than subsidies for the cost of the market in driving investment.

The question above is often motivated by three concerns regarding the standard security market design that shaped most current organized wholesale energy markets:

1. Grid Strategies LLC. [https://gridstrategiesllc.com/]
2. Regulatory Assistance Project. [https://rap.ucr.edu/]
3. This question does not address the substantial transmission infrastructural needs for a decarbonized grid. This is a more difficult challenge that also must be addressed and remains a significant issue for network planning.

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A Customer-focused Framework for Electric System Resilience

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May 2018

Papers available at www.gridstrategiesllc.com