PJM’s Evolving Resource Mix and System Reliability

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NGA 2017 Regional Market Trends Forum
May 4, 2017
2016 Existing PJM Installed Capacity

- Natural Gas, 63,347 MW
- Nuclear, 33,932 MW
- Coal, 59,679 MW
- Waste, 922 MW
- Oil, 9,839 MW
- Solar, 262 MW
- Hydro, 8,358 MW
- Wind, 1,005 MW

The numbers in this figure represent RPM-eligible “iron-in-the-ground” MW values.

December 31, 2016
PJM Queued Generation Fuel Mix – Requested Capacity Interconnection Rights

- Natural Gas, 65,614 MW
- Storage, 36 MW (Nameplate Capacity = 681 MW)
- Nuclear, 196 MW
- Other, 26 MW
- Solar, 6,990 MW (Nameplate Capacity = 15,842 MW)
- Wind, 2,223 MW (Nameplate Capacity = 14,655 MW)
- Wood, 66 MW
- Biomass, 71 MW
- Coal, 277 MW
- Hydro, 178 MW
- Methane, 52 MW

12/2016
Focus of PJM Fuel Security Whitepaper

Define fuel diversity and fuel security with a primary focus on reliability

Reflect on current makeup of PJM / U.S. fuel diversity

Analyze fuel diversity trajectory and identify avoidance areas which will negatively impact reliability

Explore fuel security and impact on reliability and fuel diversity
FOCUS

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Reflect on current makeup of PJM / U.S. fuel diversity

Explore fuel security and impact on reliability and fuel diversity

APPROACH

1. Leveraged NERC Essential Reliability Services to measure reliability
2. Establish Baseline near-term PJM portfolio
3. Establish Potential Portfolios
4. Operational Reliability Risk Assessment
5. Diversity & Reliability Indices

FINDINGS

Portfolios composed of up to 86 percent natural gas showed no decreases in reliability but increase risk in fuel security.

Portfolios with moderate wind/solar are reliable if accompanied by large shares of coal and natural gas.

As the resource mix moves in the direction of less coal and nuclear generation, frequency response, reactive capability and fuel assurance attributes decrease.
### Essential Reliability Attributes

#### Contribution of each resource type to a particular attribute

#### Qualitative approach to describing resource attributes essential for system reliability

#### Capabilities needed by the grid to ensure reliability
<table>
<thead>
<tr>
<th>Resource Type</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1</td>
</tr>
<tr>
<td>Natural Gas Steam</td>
<td>1</td>
</tr>
<tr>
<td>Natural Gas CT</td>
<td>1</td>
</tr>
<tr>
<td>Oil Steam</td>
<td>1</td>
</tr>
<tr>
<td>Oil CT</td>
<td>1</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
</tr>
<tr>
<td>Solar</td>
<td>0.5</td>
</tr>
<tr>
<td>Wind</td>
<td>IF %UCAP ≥ 5%, Index = 1&lt;br&gt;IF %UCAP &lt; 5%, Index = 0.5</td>
</tr>
<tr>
<td>Hydro</td>
<td>1</td>
</tr>
<tr>
<td>Battery / Storage</td>
<td>1</td>
</tr>
<tr>
<td>Demand Response</td>
<td>0</td>
</tr>
<tr>
<td>Other Renewable</td>
<td>1</td>
</tr>
</tbody>
</table>
1 MW w/ Attributes

- Resource 1
- Resource 2
- Resource 3
- Attribute Capability

Portfolio A

Portfolio B

UCAP
Fuel Security Risk Analysis

1. Baseline Expected Near-Term PJM Portfolio
2. Potential Portfolios
3. Operational Reliability Risk Assessment
4. Diversity & Reliability Indices
## Baseline Portfolio UCAP Composition

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>UCAP (MW)</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>57,259</td>
<td>34.3</td>
</tr>
<tr>
<td>Nuclear</td>
<td>30,271</td>
<td>18.1</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>55,462</td>
<td>33.2</td>
</tr>
<tr>
<td>Petroleum</td>
<td>10,349</td>
<td>6.2</td>
</tr>
<tr>
<td>Solar</td>
<td>127</td>
<td>0.1</td>
</tr>
<tr>
<td>Wind</td>
<td>1,086</td>
<td>0.6</td>
</tr>
<tr>
<td>Hydro</td>
<td>7,783</td>
<td>4.6</td>
</tr>
<tr>
<td>Other Renewable</td>
<td>970</td>
<td>0.6</td>
</tr>
<tr>
<td>Demand Response</td>
<td>3,759</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>167,066</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>
## Retirement-Replacement Illustrative Example

<table>
<thead>
<tr>
<th>Fuels Out</th>
<th>Fuels In</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of Coal Retired</td>
<td>% of Nuclear Retired</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
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<tr>
<td>0</td>
<td>100</td>
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<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>75</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>
CRI vs. Shannon-Wiener Diversity Index

The diagram illustrates the relationship between the Composite Reliability Index (CRI) and the Shannon-Wiener Diversity Index (SW). Points on the graph represent different levels of reliability and diversity, categorized into various groups such as Greater Than Baseline, Current, Less Than Baseline, At Risk for Underperformance, Infeasible, and Desirable. The graph segments the SW index into Low, Medium Low, Medium High, and High Fuel Diversity categories.
Distribution of the Performance Categories

- Infeasible: 11.4%
- At-Risk-for-Under Performance: 15.9%
- Desirable: 27%
- Greater-Than-Baseline: 21.4%
- Less-Than-Baseline: 51.3%

CRI Values by Portfolio Category

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Min</th>
<th>Max</th>
<th>LOLE Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infeasible</td>
<td>-</td>
<td>-</td>
<td>Failed</td>
</tr>
<tr>
<td>At-Risk-for-Under Performance</td>
<td>0.79</td>
<td>0.90</td>
<td>Met</td>
</tr>
<tr>
<td>Less-Than-Baseline</td>
<td>0.90</td>
<td>0.99</td>
<td>Met</td>
</tr>
<tr>
<td>Greater-Than-Baseline</td>
<td>1.00</td>
<td>1.11</td>
<td>Met</td>
</tr>
<tr>
<td>Desirable</td>
<td>0.95</td>
<td>1.11</td>
<td>Met</td>
</tr>
</tbody>
</table>
Reliability… Resilience

Risks / Dependencies:
- Extreme Weather
- Physical/Cyber Attacks
- Fuel Source/Security

Prepare
- Build New Infrastructure
  - RTEP: locational, criticality
  - Supplemental: aging infrastructure, local needs
- Physical & Cyber
  - Protect critical infrastructure
  - Drills with members, industry
  - Design for security

Operate
- Operations
  - Operate to manage equipment failure
  - Study pipeline, other contingencies
- Physical & Cyber
  - Monitor & reduce vulnerabilities
  - Threat info. sharing

Recover
- Operations
  - Blackstart
  - Physical & Cyber
  - BCP Plans & Golden Image
  - Coordinate with Gov’t/industry
  - Cyber mutual assistance

Future
- Build New Infrastructure
  - Resilience as a driver
- Installed Reserves
  - Incorporate risks in reserve margin
- Physical & Cyber
  - Cross-sector coordination

- Markets
  - Value flexible resources beyond reliable criteria
  - Leverage Alternative Technologies
  - Microgrids & DER
Continuing improvement in gas / electric coordination – including resilience

Valuing these and potentially other essential resource attributes into the future?

Looking at resilience in planning and operations in addition to reliability