Innovative Methods to Improve Flexibility in PJM

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PJM Interconnection
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 PJM as Part of the Eastern Interconnection

### Key Statistics

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Member companies</td>
<td>1,040+</td>
</tr>
<tr>
<td>Millions of people served</td>
<td>65</td>
</tr>
<tr>
<td>Peak load in megawatts</td>
<td>165,492</td>
</tr>
<tr>
<td>MW of generating capacity</td>
<td>178,563</td>
</tr>
<tr>
<td>Miles of transmission lines</td>
<td>84,042</td>
</tr>
<tr>
<td>2017 GWh of annual energy</td>
<td>773,522</td>
</tr>
<tr>
<td>Generation sources</td>
<td>1,379</td>
</tr>
<tr>
<td>Square miles of territory</td>
<td>243,417</td>
</tr>
<tr>
<td>States served</td>
<td>13 + DC</td>
</tr>
</tbody>
</table>

- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection

As of 2/2018
Percentage of Renewable Energy is Small but Growing

PJM Generation Mix – 2017
Annual Energy

- Nuclear, 35.9%
- Gas, 26.7%
- Coal, 32.2%
- Renewables, 5.0%
- Oil, 0.2%

MWh (millions)

- Biomass
- Solar
- Wood
- Methane
- Solid Waste
- Water
- Wind

Renewable Energy
Energy Markets / Operations
• Implemented a centralized wind power forecast service
• Solar power forecast is in progress
• Implemented changes to improve wind resource dispatch / control
• Demand Response / Price Responsive Demand improves operational flexibility
• Frequency Regulation – “pay for performance” rewards better performing resources (like storage)
• Interchange Scheduling – compliant with FERC Order 764 (15-minute intervals)

Transmission Planning
• Light load criteria implemented to improve grid reliability
• Expansion planning considers public policy impacts (i.e., RPS)
• Grid interconnection – enhanced standards for new inverter-based resources (wind and solar)

Evaluating Potential Grid Impacts
• PJM Renewable Integration Study (PRIS) - assessed grid impacts

Advanced Technology Research Program (ATRP)
• Pilot programs to evaluate new technologies and remove barriers to participation in PJM markets and operations.
PJM Renewable Integration Study shows a need for regulation reserves to increase under all scenarios, especially under High Solar scenarios.

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Load Only</th>
<th>2% BAU</th>
<th>14% RPS</th>
<th>20% HOBO</th>
<th>20% LOBO</th>
<th>20% LODO</th>
<th>20% HSBO</th>
<th>30% HOBO</th>
<th>30% LOBO</th>
<th>30% LODO</th>
<th>30% HSBO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum (MW)</td>
<td>2,003</td>
<td>2,018</td>
<td>2,351</td>
<td>2,507</td>
<td>2,721</td>
<td>2,591</td>
<td>2,984</td>
<td>3,044</td>
<td>3,552</td>
<td>3,191</td>
<td>4,111</td>
</tr>
<tr>
<td>Minimum (MW)</td>
<td>745</td>
<td>766</td>
<td>919</td>
<td>966</td>
<td>1,031</td>
<td>1,052</td>
<td>976</td>
<td>1,188</td>
<td>1,103</td>
<td>1,299</td>
<td>1,069</td>
</tr>
<tr>
<td>Average (MW)</td>
<td>1,204</td>
<td>1,222</td>
<td>1,566</td>
<td>1,715</td>
<td>1,894</td>
<td>1,784</td>
<td>1,958</td>
<td>2,169</td>
<td>2,504</td>
<td>2,286</td>
<td>2,737</td>
</tr>
<tr>
<td>% Increase Compared to Load</td>
<td>1.5%</td>
<td>30.1%</td>
<td>42.4%</td>
<td>57.3%</td>
<td>48.2%</td>
<td>62.6%</td>
<td>80.2%</td>
<td>108.0%</td>
<td>89.8%</td>
<td>127.4%</td>
<td></td>
</tr>
</tbody>
</table>
Advanced Technology Research Program
PJM Advanced Technology Research Program

- Intelligent Generation, Combination Pilot - Chicago, IL
- GM OnStar, PHEV - Detroit, MI
- Ashlawn, Flow Battery Storage - Painesville, OH
- Peri GridMax, PRD/Standards - Newark, NJ
- Northley Island (Princetown Power), Storage & Renewables - Chicago, IL
- VCharge, Combination Pilot - East Stroudsburg, PA
- Petra Solar - NJ
- SolarCity & Tesla Motors - Milford, PA
- AES, Battery Energy Storage - Laurel Mt., WV
- Timber Rock, Battery Storage & Renewables - White Marsh, MD
- Duke Envision Center - Erlanger, KY
- Xtreme Power, Combination Pilot - Delmarva Peninsula
- Sunverge, Renewables - VF, PA
- AES 2 MW PJM Battery - VF, PA
- Steffes, Thermal Energy Storage - Valley Forge, PA
- IPKeys/Walmart Automated DR/OASIS Energy Interoperation Network Demo, PRD - VF, PA
- Smart Meters, Appliances & Buildings:
  - Greenlet Tech. - VF, PA
  - Open Energi, Thermal Storage / Demand Response - VF, PA
- Viridity / SEPTA, Battery Energy Storage - Phila., PA
BMW of North America
SMART CHARGING DEMONSTRATION PROJECT

Demonstrations in Progress

Store #3475 (Trooper Road) HVAC Response

- Emergency DR Event (Avg. 145.5 kW)
- PRD Event (Avg. 136 kW)
- Curtailment

5/28/2012
5/29/2012

SolarCity

Battery and Inverters

PV Array

(Avg. 136 kW)

(Avg. 145.5 kW)

Emergency DR Event

PRD Event

(Store #3475 (Trooper Road) HVAC Response)
Grid Storage Types and Availability

- Pumped Hydro
- Compressed Air
- Flywheels
- Stationary Battery
- Mobile Batteries
- Water Heaters
105-gallon electric water heater demonstrates minimization of cost while responding to the PJM wholesale price signal and the PJM frequency regulation signal.

Power consumption
+/−2.25 kW base point

PJM Frequency Regulation Signal

Jan. 14, 2011 Midnight to 3:00 a.m.
Charging during low LMP periods following PJM frequency regulation.
<table>
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<tr>
<th>Frequency Regulation</th>
<th>Synchronized Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>262.4 MW</strong> of batteries</td>
<td><strong>444 MW</strong> of demand-side resources capable of providing</td>
</tr>
<tr>
<td><strong>23.6 MW</strong> of demand-side resources</td>
<td>synch reserve in 2017 YTD.</td>
</tr>
</tbody>
</table>

~ On average **27%**. As high as **39%** of our regulation requirement is provided by alternative technologies.

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<tbody>
<tr>
<td>8.1% of synch reserve actually provided by</td>
<td></td>
</tr>
<tr>
<td>Demand-Side Resources in 2017 YTD.</td>
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</tbody>
</table>
2018 PJM Demand Response: Regulation Registrations

- **Water Heaters**: 72%
- **Batteries**: 23%
- **HVAC**: 1%
- **Generator**: 3%
- **Manufacturing**: 0.7%

Note: Percent of CSP Reported Load Reduction MWs
2018 Economic Demand Response **Regulation** Market Participation

Note: MWh=sum of the settled MW. Example: 1 MW load available for 12 hours = 12 MWh.
2018 PJM Demand Response: Synch Reserve Registrations

Note: Percent of CSP Reported Load Reduction MWs
Note: MWh=sum of the settled MW. Example: 1 MW load available for 12 hours = 12 MWh.
Looking to the Future

• Flexible resources will be needed to offset the impacts of variable generating resources

• New market players:
  – Distributed Energy Resources
  – Smart Grid Technologies
  – Energy Storage Resources

• Potential market changes:
  – New tools to improve forecasting and scheduling capabilities
  – New market mechanisms to incent flexible resources
    • Synchronized and Operating Reserve Market Enhancements
    • Shortage Pricing
    • Fast Start Pricing
Additional Information

• PJM Initiatives:
  – PJM Learning Center: Alternative & Renewable Generation
  – PJM Renewable Integration Study (PRIS) Reports

• Other Publications:
  – Energy Systems Integration Group (EVIG)
    » https://www.esig.energy/resources/
  – National Renewable Energy Laboratory (NREL) Renewable Electricity Futures
    » https://www.nrel.gov/analysis/re_futures/index.html
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- Track power prices
- Get notifications

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