Overview of PJM: Looking Back to Look Forward
Tokyo Power Market Summit

Craig Glazer
Vice President, Federal Government Policy – PJM Interconnection
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Topics

1. PJM Overview
2. Evolution of PJM Markets
3. Day and Real Time Markets and Locational Marginal Pricing
4. Capacity Market Overview
Topics (Continued)

5. Demand Response Programs in PJM
6. Energy Storage Opportunities in PJM
7. Lessons Learned in Market Development
8. Future Challenges and Opportunities
Topic #1: PJM Overview
### Key Statistics

<table>
<thead>
<tr>
<th>Statistic</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>

- 27% of generation in Eastern Interconnection
- 27% of generation in Eastern Interconnection
- 28% of load in Eastern Interconnection
- 20% of transmission assets in Eastern Interconnection

As of 2/2018
Major Grid Operator Comparison

National Grid (UK)
61 GW, 62 m

Elia Group (Belgium)
29 GW, 30 m

KPX (South Korea)
76 GW, 50 m

MISO (USA)
98 GW, 39 m

SO UPS (Russia)
157 GW, 144 m

Tepco (Japan)
64 GW, 45 m

PJM (USA)
164 GW, 60 m

SGCC (China)
544 GW, 1,100 m

CSG (China)
129 GW, 240 m

ONS (Brazil)
77 GW, 189 m

PGCIL (India)
135 G, 1,200 m

AEMO (Australia)
35 GW, 19 m

REE (Spain)
44 GW, 46 m

Eskom (South Africa)
37 GW, 50 m

TERA (Italy)
57 GW, 60 m

RTE (France)
100 GW, 100 m

Information for each member refers to peak load and customers served.
Source: G015
PJM’s Role as a Regional Transmission Organization

Stock Market for Electricity

Energy Market Pricing

Air Traffic Controllers for the Transmission Grid

Match Generation to Load
Independent Board of Managers

Members Committee

- Independent Board of Managers
- Stakeholder process – provide balanced stakeholder input
- Established process for discussion of market evolution
- ISO funding and startup
Topic #2: Evolution of PJM Markets
Initially a ‘simple’ pricing mechanism (single zone) and trading rules to promote bilateral trading

- Minimized interaction between market incentives and physical power system operation
- Result was market failure – generators were incented to act in a manner contrary to system reliability
- PJM had to initiate emergency procedures to direct generation reductions

Market design was abandoned and replaced with flow-based Locational Marginal Pricing (LMP) system on April 1, 1998.
Introduction, and progressive evolution, of:

- Real-time locational marginal pricing (LMP) market
- Day-ahead market
- Financial transmission rights (FTR) auctions
- Resource capacity market
- Ancillary services markets
- Coordinated regional transmission expansion planning
- Demand response/distributed resource programs
Topic #3: Day Ahead and Real Time Markets and Locational Marginal Pricing
Evolution of Markets

ISO/RTO MARKETS
- Real-Time Market
- Ancillary Services
- Member to Member

ISO/RTO OPERATIONS

FINANCIAL MARKETS
- Day-Ahead Market
- Options
- Swaps
- Reliability Pricing Model
- Spreads
- Long-Term FTR Market

Heavy RTO Involvement Light
<table>
<thead>
<tr>
<th>Overall Market Timeline</th>
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</thead>
<tbody>
<tr>
<td><strong>Long Term</strong></td>
</tr>
<tr>
<td>Up to 4 years ahead</td>
</tr>
<tr>
<td></td>
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<tr>
<td>• Bilateral forward contracts/over the counter</td>
</tr>
<tr>
<td>• Transmission reservations</td>
</tr>
<tr>
<td>– ARR allocations</td>
</tr>
<tr>
<td>– Annual FTR auctions</td>
</tr>
<tr>
<td>– FTR secondary market</td>
</tr>
<tr>
<td>• Monthly FTR auctions</td>
</tr>
<tr>
<td>– Generation capacity market</td>
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www.pjm.com
Almost all modern electricity markets utilize the concept of ‘marginal pricing’:

- Represents the cost of the last flexible increment of supply.
- All buyers pay, and all sellers are paid, the marginal price, regardless of their individual bids/offers.
- Typically determined through a periodic auction, with a price set for each trading period.
Effectuating 5 Minute Settlement—2018 Initiative

- FERC Order 825 – Sub-Hourly Settlements Align settlement and dispatch intervals by: Settling energy transactions in its real-time markets at the same time interval it dispatches energy
- Settling operating reserves transactions in its real-time markets at the same time interval it prices operating reserves
- Settling intertie transactions in the same time interval it schedules intertie transactions

- Goal: Align prices with resource dispatch instructions and operating needs, providing appropriate incentives for resource performance
Locational Marginal Pricing (Nodal Pricing)

• Spot market with flow-based pricing at individual transmission buses (nodes), based on actual power system security constraints.

• Implemented via security-constrained economic dispatch (Real-Time) and security-constrained unit commitment (Day-Ahead).

LMP Timeline


2000: Implemented Day-Ahead Energy Market

2012: Shortage Pricing

LMP: A method to price energy purchases and sales

- Generators get paid at generation bus LMP
- Loads pay at load bus LMP
- Transactions pay differential between source and sink LMP

LMP = System Energy Price + Transmission Congestion Cost + Cost of Marginal Losses
Topic #4: Capacity Market Overview
2017 Total Wholesale Cost

- Energy, $31.06
- Reliability (Capacity), $8.73
- Transmission Services, $8.58
- Other Services, $1.27

Total Wholesale Cost
$49.64/MWh
PJM Capacity Market Purposes

- Ensure reliability and certainty of supply on a forward basis
- Provide a market signal to attract needed new investment
- Provide a market signal to retire uneconomic capacity
- Ensure customer bills reflect the relative value of excess supply vs. shortage
PJM Capacity Market Results:
A More Efficient, Cleaner Fleet.

• 36,031 MW of New Cleaner Energy Resources (Mostly Gas)
• 12,814 MW of Demand Response and Energy Efficiency Resources
• 36,523 MW in Retirements (Mostly Coal)
• New entry has driven prices lower — 40% reduction across PJM
Topic #5:
Demand Response Programs in PJM
### Demand Response and Energy Efficiency Opportunities in PJM Wholesale Market

<table>
<thead>
<tr>
<th>Wholesale Service</th>
<th>Demand Response</th>
<th>Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Day Ahead Scheduling Reserves (30 min)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Synchronized Reserves (10 min)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Regulation</td>
<td>Yes</td>
<td></td>
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</table>
Increasing Demand Resources in the Capacity Market
Topic #6: Emerging Energy Storage Opportunities in PJM
• Energy Storage in Ancillary Services
  – Active participation in PJM Regulation Market
• Energy Storage in Capacity Market
  – Enhanced aggregation opportunities
• Energy Storage in Energy Market
  – No barriers but limited participation outside of hydro
Laurel Mountain, WV (AES Energy Storage)
Wind + Storage
98 MW, 61 turbines +
32 MW, 8 MWh,
1.3 M cells

Total Advanced Storage
Grid Connected – 266 MW
Behind-the-Meter – 15 MW
Under Construction – 50 MW
Under Study – 630 MW

Grid-Scale Energy Storage – 250+ MW in Operation
105-gallon electric water heater demonstrates minimization of cost while responding to the PJM wholesale price signal and the PJM frequency regulation signal.
Behind the Meter - Model does not work well for behind the meter storage absent:

- Dispatchability
- Interconnection analyses
- Unit specific capacity resource identification
- Aggregation within a constrained area
Topic #7: Lessons Learned in Market Development
Lessons – Market Establishment

**Market establishment is a complex challenge, with high stakes**

Electricity market establishment programs are large, high-profile, multi-disciplinary undertakings, critical to the overall market reform agenda.

**Scope is a moving target**

Often processes are being defined, and systems specified, while the market design and rules are still being finalised. This is a frequently unavoidable reality, that must be carefully managed.

**Capability involves more than just systems**

Establishing the market involves not just complex IT, but significant organisational change and process development.
**Provide a soft landing**
Where participants are unfamiliar with market constructs, they face substantial commercial risk at market opening. Constructs such as ‘vesting’ contracts are essential in managing this.

**Lack of participant readiness is a frequent cause of market delay**
It is essential to involve participants early in the market establishment process, and frequently assess their readiness to ensure they are commercially prepared:

- Provide extensive training and certification
- Track ongoing readiness
- Conduct Market Simulations and Market Trials prior to go-live
Topic #8 (The Final Topic!):
Future Challenges and Opportunities
- Integration of distributed energy resources
- Integration of intermittent resources
- Gas / electric coordination
- Fuel security
- Forward Capacity Market and Capacity Performance to promote competitive investment
- Competitive transmission investment
Price Suppression from Government Subsidies

- Capacity Repricing: Allow subsidized units to clear but restate prices at unsubsidized levels
- Minimum Offer Pricing Rule: Establish a floor price at generator’s going forward costs without the subsidy.
Distributed Energy Resources (DER) are driving a need for better:
• visibility
• measurement and forecasting
• control and market integration
… at a lower level of the grid.

The Philadelphia Navy Yard is a 1,200 acre micro-grid site with mixed industrial and commercial usage.
Gas/Electric Coordination and Fuel Security

- Increased usage of gas creates significant gas/electric interdependencies
- Far more dynamic gas usage than system originally designed for.
- Seeing increased gas deliverability constraints – impacting fuel security for electric system.
LET'S TALK…

Craig Glazer  
Vice President-Federal Government Policy  
PJM Interconnection  
Washington, D.C., USA  
1-202-423-4743  
craig.glazer@pjm.com