PJM Proposed Package

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Real-Time Market Operations
Regulation Market Design Senior Task Force
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MATRIX ITEMS:

A: Regulation Signal
   1. Signal type
   2. Product type

https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2023/20230124/item-03-reg-signal-presentation-1242023.ashx

https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2023/20230124/item-04-regulation-regupdown-1242023.ashx
A single signal regulation design will allow PJM to better reflect the system needs to the regulation fleet to provide regulation service.

- Resource agnostic signal aligned with system needs
- Allows a simpler implementation for dispatch to operate and track; today’s Reg A/D construct is not always clear on what regulation is available.
- Allows for additional products to be developed (regulation up/down). Removing the two signal complexity would allow for an easier transition to RegUp and RegDn under one signal
Product Type: RegUp & RegDn

• Implement Regulation Up and Regulation Down Products
  – One market two separate products with separate requirements and clearing prices
  – Resources would be able to offer, clear and provide both products together, or can provide just one product within the same regulation clearing duration

• Regulation up/down products will allow PJM to better address system needs in the future
  – PJM would have the ability to procure more or less of one product, depending on changing system needs
  – RegUp/Dn products would allow the broadest set of resources to provide regulation service
  – Market efficiency on available resource capabilities, minimized LOC and overall production cost
RegUp/RegDn

- RegUp product operates above the zero crossing
- RegDn product operates below the zero crossing
- Operationally, one product will be fully deployed and undeployed before the other product is asked to respond to an AGC signal
Two Units Example (Bi-directional Signal)

### Table: Two Units Example (Bi-directional Signal)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Load</th>
<th>Reg Req.</th>
<th>Energy, MW (price)</th>
<th>Reg, MW (price)</th>
<th>LMP ($/MWh)</th>
<th>LOC ($/MWh)</th>
<th>Total Production Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>5</td>
<td>35 (35)</td>
<td>15 (75)</td>
<td>75</td>
<td>40</td>
<td>3950</td>
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<tr>
<td>2</td>
<td>50</td>
<td>20</td>
<td>30 (30)</td>
<td>20 (100)</td>
<td>100</td>
<td>70</td>
<td>6400</td>
</tr>
</tbody>
</table>

LOC (1A) = |LMP – MC| x (Desired MW @ LMP – Reg-Set-point) / RegMW = (75-35)*(40-35)/5 = 40

Total Production Cost (1) = Energy Cost + Regulation Cost = (50*75) + (5*40) = $3950

Total Production Cost (2) = Energy Cost + Regulation Cost = (50*100) + (20*70) = $6400
Two Units Example (RegUp/Dn Design)

<table>
<thead>
<tr>
<th></th>
<th>MW</th>
<th>Offer Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcoMin</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>EcoMax</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

Assume Requirement RegUp=RegDown

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Load</th>
<th>Reg Req.</th>
<th>Energy, MW (price)</th>
<th>RegUp, MW (price)</th>
<th>RegDn, MW (price)</th>
<th>LMP</th>
<th>RegUp LOC</th>
<th>RegDn LOC</th>
<th>Total Production Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resources</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>5</td>
<td>40 (40)</td>
<td>10 (50)</td>
<td>0 (0)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2500</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>20</td>
<td>40 (40)</td>
<td>10 (50)</td>
<td>0 (0)</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>2500</td>
</tr>
</tbody>
</table>

LOC (1ADn) = |LMP – MC| x (Desired MW @ LMP – Reg-Set-point) / RegMW
= (50-40)*(40-40)/5 = 0

Compared with bi-directional design:
- Less Energy Cost
- Less Regulation/LOC Cost
RegUp/RegDn Design Summary

- Differentiate system needs – Different Up/Down Requirements
- Promote new market entry
- Provide flexibility of supply
- Potential decrease on system production cost, LOC and Regulation clearing price
MATRIX ITEMS:
B: Regulation Requirement


https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2023/20230222/20230222-item-03---pjm-regulation-requirement-proposal.ashx

https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2023/20230418/20230418-item-03---regulation-requirement.ashx
Regulation Requirement: Revised Proposal

- Similar to status quo, bi-level regulation requirement MW dependent on season and hour of day
- Influenced by recent ACE and CPS historic data (2022)
- Modifies to the status quo to align with observed control outcomes
  1. Shifts in seasonal definitions based on grouping months with similar hourly profiles
  2. Changes in “high” and “low” designated hours
  3. Minor change in “high” and “low” designated MW levels
# Summary of Regulation Requirement Proposal

<table>
<thead>
<tr>
<th>Season</th>
<th>Dates</th>
<th>Hours Ending</th>
<th>Requirement MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Nov. 1 – Feb. 28</td>
<td>HE 5 – 10, HE 17 – 24</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HE 1 – 4, HE 11 - 16</td>
<td>500</td>
</tr>
<tr>
<td>Spring</td>
<td>March 1 - April 30</td>
<td>HE 19 – 1, HE 6 – 9</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HE 2 – 5, HE 10 – 18</td>
<td>500</td>
</tr>
<tr>
<td>Summer</td>
<td>May 1 – Sept. 15</td>
<td>HE 5 – 15, HE 20 – 1</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HE 2 – 4, HE 16 - 19</td>
<td>500</td>
</tr>
<tr>
<td>Fall</td>
<td>Sept. 15 – Oct. 31</td>
<td>HE 6 – 9, HE 18 – 24</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HE 1 – 5, HE 10 - 17</td>
<td>500</td>
</tr>
</tbody>
</table>
This design component is not developed because PJM proposed package is based on a single signal design rather than RegA and RegD or two signal design. As such, the conversion relationship between signals is no longer relevant.
MATRIX ITEMS:
E: Performance Scoring
14. Qualification testing
15. Type specific testing
16. Components of performance scoring and weight
   16c. Precision score calculation
17. Minimum allowable participation threshold
18. Minimum allowable compensation threshold

https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2022/20221019/item-05---regulation-testing-process-overview.ashx

Regulation Testing Proposal

Disqualified Resources

Change in Capability (MW)

Change in Communication Path or EMS – Existing or New Owner/MOC

New Resources

1 PJM-administered test

2 tests = 1 self-scheduled test + 1 PJM-administered test or 2 PJM-administered tests

New Performance Score of (an average of) PJM-administered test(s)
16. Components of performance scoring and weighting
   – 100% Precision score
   – Precision score calculation will be status quo precision score formula
     ❖ The instantaneous error between the control signal and the regulating unit’s response

\[
Error = \text{Avg of Abs} \frac{\text{Response} - \text{Regulation Signal}}{\text{Hourly Average Regulation Signal}}
\]

\[
\text{Precision Score} = 1 - \frac{1}{n} \sum \text{Abs}(Error)
\]

17. Minimum allowable participation threshold - status quo
   – 40% historic performance score (average across last 100 operating hour)

18. Minimum allowable compensation threshold – status quo
   – 25% performance (precision) score for the interval
MATRIX ITEMS:

G: Mileage

21. Calculation of Mileage
21. Calculation of Mileage

- Mileage is the signal movement in support of ACE control
- Mileage will be calculated as the absolute sum of movement of the regulation control signal in a given time period.
- RegUp mileage will be separate from RegDn mileage

\[
\text{Mileage}_{\text{RegUp}} = \sum_{i=1}^{n} |\text{RegUp}_i - \text{RegUp}_{i-1}|
\]

\[
\text{Mileage}_{\text{RegDn}} = \sum_{i=1}^{n} |\text{RegDn}_i - \text{RegDn}_{i-1}|
\]

A full deploy and un-deploy = 2 miles
Use of Mileage

• Regulation clearing and regulation pricing will use the daily (historical) product signal mileage for the mileage offer price adjustment
  – Historical mileage is a rolling 30-day average by the product signal type

• Settlement will use the ratio of the 5-minute product signal actual mileage to the product historic mileage for the Regulation Mileage (Performance) credit
  – For RegUp: \( \frac{\text{RegUp signal actual 5-minute mileage}}{\text{RegUp historic mileage for the operating day}} \)
  – For RegDn: \( \frac{\text{RegDn signal actual 5-minute mileage}}{\text{RegDn historic mileage for the operating day}} \)

  ⚫ Note that the ratio is dimensionless
  ⚫ Proposing to rebrand Performance price/credit to Mileage price/credit
MATRIX ITEMS:

D. Lost Opportunity Cost
12. Schedule used for LOC
13. Use of desired MW at LMP vs desired MW at ramp limited

https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2022/20220920/item-05---regulation-lost-opportunity-cost---overview.ashx

https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2023/20230222/20230222-item-06---regloc---enhanced-calculation-of-the-desired-mw-at-lmp-ramp-rate-limited.ashx
Lost Opportunity Cost (LOC)

- Energy schedule used for LOC
  - For online resources, the schedule on which the resource is committed and running for energy
  - For offline resources, the cheapest of the price-based or cost-based available energy schedules
- Total LOC Calculation
  Area bounded by LMP, tracking desired MW @ LMP ramp limited, marginal cost @ Reg set point and MW @ Reg set point minus area bounded by energy schedule curve, tracking desired MW @ LMP ramp limited, marginal cost @ Reg set point and MW @ Reg set point.
Desired MW @ LMP vs Desired MW @ LMP Ramp Limited

• The **Desired MW at LMP** is not ramp limited, and not based on the initial MW of the unit – status quo:
  – Generally overvalues LOC

• The **Desired MW @ LMP Ramp Limited** is based on the Initial MW and the ramp capability of the unit:
  – When a unit does not follow the dispatch signal well, the Dispatch MW at Ramp Limited does not reflect where the unit should have been.
    ❖ The LOC is at times undervalued
  – The Desired MW at LMP Ramp Limited should account for the resource’s pnode LMP profile and impact of the confined regulation range
Proposed Tracking Desired MW @ LMP Ramp Limited

- A Tracking Desired MW @ LMP Ramp Limited will incorporate consecutive market conditions to create the profile that units should have achieved if they had been following each dispatch signal based on their ramp rates.
  - This metric will calculate continuously from when a unit comes online, using its ramp rates, energy schedule, and independent of the initial MW at each interval.

<table>
<thead>
<tr>
<th>LMP</th>
<th>Desired MW @ LMP</th>
<th>Desired MW @ LMP Ramp Limited</th>
<th>Tracking Desired MW @ LMP Ramp Limited</th>
<th>Total LOC @ LMP</th>
<th>Total LOC @ LMP Ramp Limited</th>
<th>Total LOC @ Tracking LMP Ramp Limited</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>230</td>
<td>250</td>
<td>280</td>
<td>490</td>
<td>350</td>
<td>140</td>
</tr>
<tr>
<td>38</td>
<td>380</td>
<td>350</td>
<td>330</td>
<td>640</td>
<td>400</td>
<td>240</td>
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<td>500</td>
<td>350</td>
<td>380</td>
<td>5000</td>
<td>1250</td>
<td>2000</td>
</tr>
<tr>
<td>47</td>
<td>470</td>
<td>350</td>
<td>430</td>
<td>2890</td>
<td>850</td>
<td>2210</td>
</tr>
</tbody>
</table>

Ramp Rate = 10 MW/min  
Reg Set point = 300 MW  
Marginal Cost @ Reg set point = $30/MWh

Total LOC (LMP) = |LMP – MC| x (Desired MW @ LMP – Reg Set-point)
Total LOC (LMP_RL) = |LMP – MC| x (Desired MW @ LMP_RL – Reg Set-point)
Total LOC (LMP_TRL) = |LMP – MC| x (Desired MW @ LMP_TRL – Reg-Set-point)
LOC Calculation

PJM package proposes area abeg minus area afg.

The LOC ($/MW) = (area abeg minus area afg)/RegMW
H: Offer Structure

22. Components of Offer

22a. Inclusion of VOM in Regulation Offer

22b. Adjusted capability offer definition

22c. Adjusted performance offer definition

23. Dual offer capability/process

24. Clearing timing

24a. Regulation range

25. Commitment process

https://www.pjm.com/-/media/committees-groups/task-forces/rmdstf/2023/20230222/20230222-item-04---rmdstf-regulation-cost-offer-formation.ashx

The $/ΔMW will be multiplied by the signal mileage in ΔMW/MW to convert to ($/MW).

Participant supplies PJM with Performance Offer, Capability Offer, and MW Offer.

Offers cannot be negative, and the capability cost offer is mandatory to be eligible to clear.
Regulation Adjusted Offers and Parameters

### Adjusted Regulation Capability Cost ($/MW)

\[
\text{Adjusted Regulation Capability Cost} = \frac{\text{Capability Offer}}{\text{Resource Historic Performance Score}} \times \frac{\text{Mileage Offer}}{\Delta MW} 
\]

### Adjusted Lost Opportunity Cost ($/MW)

\[
\text{Adjusted Lost Opportunity Cost} = \left( \frac{\text{Lost Opportunity Cost}}{\text{Resource Historic Performance Score}} \right) + \left( \frac{\text{Adjusted Mileage Cost}}{\Delta MW} \right)
\]

### Adjusted Total Cost ($/MW)

\[
\text{Adjusted Total Cost} = \text{Adjusted Regulation Capability Cost} + \text{Adjusted Lost Opportunity Cost} + \text{Adjusted Mileage Cost}
\]

- **Historical Performance Score** – average of last 100 hours of resource’s performance scores
- **Historical Mileage** – 30 days average of PJM regulation control signal-type mileage

- **Regulation Effective MW**

\[
\text{Regulation Effective MW} = \text{Regulation MW} \times \text{Historic Performance Score}
\]

- Same adjusted offers and parameters will be used in pricing
Dual Offers and De-commitment

• RegUp only resource will follow regulation signal above the zero crossing only
• RegDn only resource will follow regulation signal below the zero crossing only
• RegUp/RegDn resource may submit offers into (and clear in) both RegUp and RegDn markets for the same interval
  – Option available for Market Participants around the clearing constraint
• Self de-assign will result in zero performance score in the regulation market interval
• PJM dispatch de-assign does not impact performance score in the regulation market interval
Open Regulation Range Requirement

• All resources participating in both energy and regulation must submit:
  – EcoMin = RegMin and EcoMax = RegMax
  – Exception request with documentation if physical operational limitation exist
    ❖ Must renew annually

• Resources with large separation between Eco-range and Reg-range incur higher LOC or uplift, and increases overall production cost
  – Reduces clearing opportunity

• Resources with small or no separation between Eco-range and Reg-range incur low or no LOC
  – Increases change of clearing
Market Clearing Time & Commitment Duration – Status Quo & Proposal

**Status Quo**
- 60 minutes prior to target time.
- Looks ahead 60 minutes beyond target time.

**Proposed**
- 30 minutes prior to target time.
- Looks ahead 30 minutes beyond target time.
- Case execution time
- Case Approval
Regulation Clearing & Pricing Summary

**Ancillary Services Optimizer (ASO)**
Clearing and assignment of regulation and inflexible reserve resources (solved 30 minutes prior to target time, looks ahead 30 minutes beyond target time)

**Locational Pricing Calculator (LPC)**
5-minute energy and ancillary service prices based on latest approved RT SCED case

**Participant Data of a Regulation Resource**
- Capability Offer ($/MW)
- Mileage Offer ($/MW)
- Regulation Offer (MW)

**PJM Calculated Data**
- Resource Specific RTO Regulation Signal
  - Resource Specific Historical Performance Score (last 100 hrs, average)
  - Historical Signal Type Mileage (rolling 30 days average)

**PJM RTO Regulation Requirement**

**Joint Co-optimization of Energy, Reserve and Regulation**

**Total Incremental Cost of Regulation Marginal Resource**

**Regulation Market Clearing Price (RMCP)**
- Mileage Clearing Price (MCP)
  - Highest Adjusted Mileage Offer of Committed Resources
- Capability Clearing Price (CCP)
  - Residual of Total Incremental Cost of Marginal Resource
MATRIX ITEMS:

F: Settlement
20. Settlement components
Settlement Components

- 5-minute pricing (status quo)
- RegUp Settlement
  - RegUp capability credit
  - RegUp mileage credit
- RegDn Settlement
  - RegDn capability credit
  - RegDn mileage credit
Settlement Components (2)

- Capability Credit = \( \frac{5\text{-minute integrated Regulation MW} \times 5\text{-minute performance score} \times 5\text{-minute Capability Clearing Price}}{12} \)

- Mileage Credit = \( \frac{5\text{-minute integrated Regulation MW} \times 5\text{-minute performance score} \times \frac{\text{signal actual 5-minute mileage}}{\text{signal historic mileage for the operating day}} \times 5\text{-minute Mileage Clearing Price}}{12} \)

  - Proposed Implementation: starting value of each signal’s historic mileage = 1
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Secretary: Wenzheng Qiu, Wenzheng.Qiu@pjm.com
SME/Presenter: Michael Olaleye, Michael.Olaleye@pjm.com

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