This Session

- System ramping capability and needs
- Manual actions
- Multi-period dispatch
- Ramp products
- Key takeaways

Portions of this presentation are adapted from ISO New England’s “Real-Time Price Formation: Pre-ramping, Technical Session #10” (4/8/2015).
Format of These Sessions

• This is NOT a Markets Committee meeting and will not follow normal MC rules (posting, interactive WebEx, etc.)
• Sessions are meant to help the ISO frame the problem and potential solution set. ALL input is welcome and essential
• We may use flip charts, white boards, or similar tools to help facilitate the discussion
• We will end the session by summarizing issues and items for further discussion and analysis
SYSTEM RAMPING CAPABILITY AND NEEDS
What is system ramping capability?

- Maximum ability of generators to change output over a specified time horizon
  - Examples: Unit dispatchable range given current output, reserve capabilities

- Generally thought of as “upward” (*ramp-up*) but can also be “downward” (*ramp-down*)
  - Since shutting down units is usually not problematic, ramp-down capabilities were historically ignored

- This presentation will focus on the ramping capability of supply-side dispatchable resources, but demand could also provide ramping capability in theory
Why is system ramping capability needed?

• Generation must always balance load \(\rightarrow\) reliability

• Reliability is affected by
  – Forecasted changes
    • Start-ups/shut-downs
    • Load
  – Uncertainty
    • Variable (intermittent) generation
    • Generator contingencies
Real-time (RT) dispatch: ISO New England

- Single-period optimization problem
  - Executed at ~10 minute intervals
  - Dispatch for ~15 minutes in the future (the “look-ahead”)

Legend:
- Look-ahead period, price USED for settlement

Diagram showing RT problem solved at various times (0, 10, 20, 30, 40) on a timeline.
Real-time (RT) dispatch: ISO New England

• Can this single-period approach result in system ramping problems?

Yes! It doesn’t consider the future (beyond ~15 minutes)

Consequences may include
  – Energy imbalance
  – Reserve and transmission violations
Single-period dispatch: Example

- System requirements

<table>
<thead>
<tr>
<th></th>
<th>Time 0 (Initial)</th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (MW)</td>
<td>250</td>
<td>252</td>
<td>280</td>
</tr>
<tr>
<td>Operating Reserve requirement (MW)</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
</tbody>
</table>

- Other assumptions
  - Only 30-Minute Operating Reserve (TMOR)
  - Operating Reserve penalty price = $1,000/MWh
  - Units follow dispatch signals perfectly
Single-period dispatch: Example

- Unit properties

<table>
<thead>
<tr>
<th></th>
<th>Unit 1</th>
<th>Unit 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offer $$/MWh</td>
<td>$60/$MWh 0 – 100MW</td>
<td>$180/$MWh 0 – 300MW</td>
</tr>
<tr>
<td>EcoMin (MW)</td>
<td>10</td>
<td>170</td>
</tr>
<tr>
<td>EcoMax (MW)</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>Ramp rate (MW/min)</td>
<td>2</td>
<td>1.333</td>
</tr>
<tr>
<td>Time 0 output (MW)</td>
<td>80</td>
<td>170</td>
</tr>
</tbody>
</table>
Single-period dispatch: Example

1: Time 0
- 80 (DDP)
- 20 (TMOR)

2: Time 15
- 100
- 50

- Load increases by 2MW at Time 15
- Based on initial conditions and parameters, feasible dispatch ranges are shown in yellow

Load = 252MW
Op Res req = 55MW
**Single-period dispatch: Example**

1. **Time 0**
   - 20 (TMOR)
   - 80 (DDP)
   - +20MW
   - -30MW

2. **Time 15**
   - 18 (TMOR)
   - 82 (DDP)
   - $60/MWh

   - +20MW
   - $180/MWh
   - -30MW
   - -20MW

   - 40 (TMOR)
   - 170 (DDP)
   - +20MW
   - -0MW

   - 40 (TMOR)
   - 170 (DDP)
   - $180/MWh

**Load = 252MW**

**Op Res req = 55MW**

- Unit 1 is dispatched up 2MW
Single-period dispatch: Example

Prices for Time 15

- The energy price (LMP) and the TMOR price (RMCP) are determined by the marginal cost of serving energy and reserves, respectively
  - LMP = $60/MWh (Unit 1 ↑ 1MW)
  - RMCP = $0/MWh

- Assume that uplift is calculated for each dispatch interval separately
  - Unit 1 is breaking even → Uplift = $0
  - Unit 2 is losing money → Cost = $7,650; Revenue = $2,550 → Uplift = $5,100
Single-period dispatch: Example

- Load increases by 28MW at Time 30
Single-period dispatch: Example

1.

- **Time 0**
  - 20 (TMOR)
  - 80 (DDP)
  - Load = 252MW
  - Op Res req = 55MW

2.

- **Time 15**
  - 18 (TMOR)
  - 82 (DDP)
  - Load = 280MW
  - Op Res req = 55MW

- **Time 30**
  - 10 (TMOR)
  - 90 (DDP)

- The system must sacrifice reserve to preserve the energy balance.

- Operating Reserve violation of 5MW in Time 30 solution.
Single-period dispatch: Example

Prices for Time 30

- The LMP and RMCP are determined by the marginal cost of serving energy and reserves, respectively
  - LMP = $1,060/MWh  
    (Unit 1 ↑ 1MW, Res violation ↑ 1MW)
  - RMCP = $1,000/MWh  
    (Res violation ↑ 1MW)

- Assume that uplift is calculated for each dispatch interval separately
  - Neither unit requires uplift
### Single-period dispatch: Example

- Production cost (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 cost ($)</td>
<td>1,230</td>
<td>1,350</td>
</tr>
<tr>
<td>Unit 2 cost ($)</td>
<td>7,650</td>
<td>8,550</td>
</tr>
<tr>
<td>Op Res violation ($)</td>
<td>0</td>
<td><strong>1,250</strong></td>
</tr>
<tr>
<td>Total cost ($)</td>
<td></td>
<td>20,030</td>
</tr>
</tbody>
</table>
Single-period dispatch: Example

- Load payments (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Energy ($)</th>
<th>TMOR ($)</th>
<th>Uplift ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>25,080</td>
<td>2,500</td>
<td>0</td>
<td>27,580</td>
</tr>
<tr>
<td>Unit 2</td>
<td>52,900</td>
<td>10,000</td>
<td>5,100</td>
<td>68,000</td>
</tr>
<tr>
<td>Total</td>
<td>77,980</td>
<td>12,500</td>
<td>5,100</td>
<td>95,580</td>
</tr>
</tbody>
</table>

- Dispatch-following incentives of LMPs and RMCPs (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Unit 2</td>
<td>❌</td>
<td>✔️</td>
</tr>
</tbody>
</table>

$5,100 NCPC
Single-period dispatch: Example

- Was the Operating Reserve shortage at Time 30 preventable?
  - Yes, preventive actions could have been taken
  - This presentation will describe several such actions and their market consequences
Core principle

- **EVERY ISO** has its own method of ensuring reliability in the face of forecasted changes and uncertainty

- Core principle of each approach:

  **Incorporate future information/uncertainties in the dispatch problem**

  - The chosen approach affects prices, dispatch quantities, total incremental cost, and out-of-market payments
Presentation structure: A Road Map

• Existing ISO solutions
  2. Multi-period dispatch (NYISO, CAISO)
  3. Ramp products (MISO, CAISO)

• The following aspects will be discussed
  – ISO-specific motivation
  – Method and example
  – Pros/Cons
  – Observations in practice (if available)
  – Conclusion

• The next Technical Session will present alternative approaches
SOLUTION 1. MANUAL ACTIONS
Motivation in ISO New England

• Historically, the system’s ramping capability was occasionally too low during periods of rapidly increasing load
  – Ramping needs were driven by steep net load increases, especially on winter mornings and before evening peaks

• Operators moved slow-ramping generators out-of-rate (upward) for 2-4 hours

• This behavior was called *preramping* because slow-ramping units were being moved early

• While these actions can help avoid reserve shortages, they have important market impacts
ISO New England practice

- Operators can preramp units by manually modifying the RT dispatch problem in one of two ways

1. Manual DDP method
   - Issue a Manual DDP to the slow-ramping unit

2. Reserve Bias method
   - Increase the Operating Reserve requirement

- ISO New England’s manual actions reflect Operator beliefs about forecasted changes and uncertainty
ISO New England practice

• How do these manual actions affect
  – Prices
  – Dispatch quantities
  – Total incremental cost
  – Out-of-market payments
Manual DDP method: Description

1. The Operator sets a [higher] Manual DDP for a specific unit prior to a potential reserve violation

2. In the dispatch solution, the unit’s DDP will be as close as feasible to the Manual DDP

• Benefits depend on the “correctness” of the Manual DDP
  – Would the Manual DDP solve the preramping problem?
  – Is the dispatch solution economically efficient?

• In practice, Operators issue Manual DDPs based on the unit’s maximum ramp rate
Manual DDP method: Example

1. Time 0
   - 80 (DDP)
   - 170 (DDP)

   20 (TMOR)

2. Time 15
   - 50
   - 100

   +20MW
   -30MW

   +20MW
   -0MW

   -40 (TMOR)

- Operator sends a 190MW Manual DDP to Unit 2
Manual DDP method: Example

1. Time 0
   - 80 (DDP)
   - 20 (TMOR)

2. Time 15
   - 62 (DDP)
   - 38 (TMOR)

- Operator sends a 190MW Manual DDP to Unit 2
- Unit 1 output is lower than in the single-period dispatch solution
- Unit 2 output is higher than in the single-period dispatch solution

Load = 252MW
Op Res req = 55MW
Manual DDP method: Example

Prices for Time 15

• The LMP and RMCP are determined by the marginal cost of serving energy and reserves, respectively
  – LMP = $60/MWh (Unit 1 ↑ 1MW)
  – RMCP = $0/MWh

• Assume that uplift is calculated for each dispatch interval separately
  – Unit 1 is breaking even → Uplift = $0
  – Unit 2 is losing money → Cost = $8,550; Revenue = $2,850
    → Uplift = $5,700
Manual DDP method: Example

1. **Time 0**
   - 80 (DDP)
   - 20 (TMOR) +20MW
   - -30MW

2. **Time 15**
   - 62 (DDP)
   - 38 (TMOR) +30MW
   - -30MW
   - $60/MWh

3. **Time 30**
   - 32
   - 92

   - 170 (DDP)
   - 40 (TMOR) +20MW
   - -0MW
   - +20MW
   - -20MW
   - $180/MWh

   - 190 (DDP)
   - 40 (TMOR) +20MW
   - -20MW
   - 210
   - 170

   - Load = 252MW
   - Op Res req = 55MW

   - Load = 280MW
   - Op Res req = 55MW

- Operator removes the Manual DDP
  - Reserve shortage at Time 30 is not a concern given outputs at Time 15
Manual DDP method: Example

1. **Time 0**
   - 80 (DDP)
   - 20 (TMOR)
   - Load = 252MW
   - Op Res req = 55MW
   - $60/MWh

2. **Time 15**
   - 62 (DDP)
   - 38 (TMOR)
   - $60/MWh
   - $180/MWh
   - +20MW
   - -30MW
   - +30MW
   - -30MW

3. **Time 30**
   - 190 (DDP)
   - 40 (TMOR)
   - 85 (DDP)
   - 40 (TMOR)
   - 195 (DDP)
   - $180/MWh
   - $180/MWh
   - +20MW
   - -20MW
   - +20MW
   - -30MW

**Notes:**
- Operator removes the Manual DDP
- Unit 1 can provide more ramping than in the single-period dispatch solution without decreasing its TMOR below 15MW
- Operating Reserve violation at Time 30 is avoided
Manual DDP method: Example

Prices for Time 30

• The LMP and RMCP are determined by the marginal cost of serving energy and reserves, respectively
  – LMP = $180/MWh (Unit 2 ↑ 1MW)
  – RMCP = $120/MWh (Unit 1 ↓ 1MW, Unit 2 ↑ 1MW)

• Assume that uplift is calculated for each dispatch interval separately
  – Neither unit requires uplift
Manual DDP method: Example

• Production cost (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 cost ($)</td>
<td>930</td>
<td>1,275</td>
</tr>
<tr>
<td>Unit 2 cost ($)</td>
<td>8,550</td>
<td>8,775</td>
</tr>
<tr>
<td>Op Res violation ($)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total cost ($)</td>
<td>19,530</td>
<td></td>
</tr>
</tbody>
</table>

– Single-period dispatch: $20,030 (with Operating Reserve violation)

• Manual DDP method is more efficient than the single-period dispatch method and avoids a Time 30 Operating Reserve violation
Manual DDP method: Example

• Load payments (remember 15-minute periods)

<table>
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<th>TMOR ($)</th>
<th>Uplift ($)</th>
<th>Total ($)</th>
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</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>4,755</td>
<td>450</td>
<td>0</td>
<td>5,205</td>
</tr>
<tr>
<td>Unit 2</td>
<td>11,625</td>
<td>1,200</td>
<td>5,700</td>
<td>18,525</td>
</tr>
<tr>
<td>Total</td>
<td>16,380</td>
<td>1,650</td>
<td>5,700</td>
<td>23,730</td>
</tr>
</tbody>
</table>

• Dispatch-following incentives of LMPs and RMCPs (remember 15-minute periods)

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<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Unit 2</td>
<td>❌ $5,700 NCPC</td>
<td>✔️</td>
</tr>
</tbody>
</table>

Time 15: √ Time 30: ✔️
Manual DDP method: Pros

- Can help preserve ramping capabilities/avoid reserve shortages
- Can be more efficient than single-period dispatch
- Easy to understand
- Does not change system reserve requirements
Manual DDP method: Cons

• Reliance on Operator intuition and experience
  – Difficult to achieve economic efficiency
  – Operator-dependent outcome

• Market-clearing prices tend to be depressed when slow-ramping units are moved up early
  – Lack of dispatch-following incentives for preramped units absent uplift
  – Generally higher uplift
Reserve Bias method: Description

1. The Operator increases the system Operating Reserve requirement prior to a potential reserve violation.

2. The dispatch solution will generally have higher DDPs for slow-ramping units and lower DDPs for fast-ramping units:
   - Reliability benefits depend on the selected Reserve Bias, actual net load ramp, unit capabilities, etc.
   - In practice, Operators choose the Reserve Bias by trial-and-error.
Reserve Bias method: Example

- Operator uses a 10MW Reserve Bias

1. **Time 0**
   - 20 (TMOR) +20MW
   - 80 (DDP) -30MW

2. **Time 15**
   - 100
   - 50

3. **2:**
   - 40 (TMOR) +20MW
   - 170 (DDP) -0MW

Load = 252MW
Op Res req = 55MW + 10MW
Reserve Bias method: Example

1. **Time 0**
   - 20 (TMOR)
   - 80 (DDP)
   - +20MW
   - -30MW

2. **Time 15**
   - 25 (TMOR)
   - 75 (DDP)
   - $60/MWh

- Load = 252MW
- Op Res req = 55MW + 10MW

- 40 (TMOR)
- 170 (DDP)
- +20MW
- -0MW

- 40 (TMOR)
- 177 (DDP)
- $180/MWh

1. **Operator uses a 10MW Reserve Bias**
2. **Unit 1 output is **lower** than in the single-period dispatch solution**
3. **Unit 1 output is **higher** than in the Manual DDP method solution**
Reserve Bias method: Example

Prices for Time 15

• The LMP and RMCP are determined by the marginal cost of serving energy and reserves, respectively
  – LMP = $180/MWh  (Unit 2 ↑ 1MW)
  – RMCP = $120/MWh  (Unit 1 ↓ 1MW, Unit 2 ↑ 1MW)

• Assume that uplift is calculated for each dispatch interval separately
  – Neither unit requires uplift
Reserve Bias method: Example

1: Time 0
- 80 (DDP)
- 20 (TMOR)

2: Time 15
- 75 (DDP)
- 25 (TMOR)

- 20 (TMOR)
- 40 (TMOR)

3: Time 30
- 177 (DDP)
- 170 (DDP)

- 100
- 45

- 197
- 170

- $60/MWh
- $180/MWh

- +20MW
- +25MW
- +20MW

- -30MW
- -30MW
- -7MW

- Load = 280MW
- Load = 252MW

- Op Res req = 55MW + 10MW
- Op Res req = 55MW

- Operator removes the Reserve Bias
- Reserve shortage at Time 30 is not a concern given outputs at Time 15
Reserve Bias method: Example

1. **Time 0**
   - Load = 280MW
   - Op Res req = 55MW + 10MW
   - 20 (TMOR)
   - 80 (DDP)
   - +20MW
   - -30MW

2. **Time 15**
   - Load = 252MW
   - Op Res req = 55MW
   - 25 (TMOR)
   - 75 (DDP)
   - +25MW
   - -30MW
   - $60/MWh

3. **Time 30**
   - Load = 280MW
   - Op Res req = 55MW
   - 85 (DDP)
   - 195 (DDP)
   - 15 (TMOR)
   - +20MW
   - -7MW
   - $60/MWh

- Operator removes the Reserve Bias
- Unit 1 can provide more ramping than in the single-period dispatch solution without decreasing its TMOR below 15MW
- Operating Reserve violation at Time 30 is avoided
Reserve Bias method: Example

Prices for Time 30

• The LMP and RMCP are determined by the marginal cost of serving energy and reserves, respectively
  – LMP = $180/MWh  (Unit 2 ↑ 1MW)
  – RMCP = $120/MWh  (Unit 1 ↓ 1MW, Unit 2 ↑ 1MW)

• Assume that uplift is calculated for each dispatch interval separately
  – Neither unit requires uplift
Reserve Bias method: Example

- Production cost (remember 15-minute periods)

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<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 cost ($)</td>
<td>1,125</td>
<td>1,275</td>
</tr>
<tr>
<td>Unit 2 cost ($)</td>
<td>7,965</td>
<td>8,775</td>
</tr>
<tr>
<td>Op Res violation ($)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total cost ($)</td>
<td></td>
<td>19,140</td>
</tr>
</tbody>
</table>

- Single-period dispatch: $20,030 (with Operating Reserve violation)
- Manual DDP method: $19,530

- Reserve Bias method is more efficient than the Manual DDP method and avoids a Time 30 Operating Reserve violation
Reserve Bias method: Example

- Load payments (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Energy ($)</th>
<th>TMOR ($)</th>
<th>Uplift ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>7,200</td>
<td>1,200</td>
<td>0</td>
<td>8,400</td>
</tr>
<tr>
<td>Unit 2</td>
<td>16,740</td>
<td>2,400</td>
<td>0</td>
<td>19,140</td>
</tr>
<tr>
<td>Total</td>
<td>23,940</td>
<td>3,600</td>
<td>0</td>
<td>27,540</td>
</tr>
</tbody>
</table>

- Dispatch-following incentives of LMPs and RMCPs (remember 15-minute periods)

<table>
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<tr>
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<th>Time 15</th>
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<td>Unit 1</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Unit 2</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
Reserve Bias method: Pros

- Can help preserve ramping capabilities/avoid reserve shortages
- Easy to understand
- Preramping induced by economic market clearing → decisions reflected in prices
  - Dispatch-following incentives preserved
  - Generally lower uplift
Reserve Bias method: Cons

- May not always induce the desired dispatch
- Reliance on Operator intuition and experience
  - Difficult to achieve economic efficiency
  - Operator-dependent outcome
- Operators are buying the ‘wrong’ product at the ‘wrong’ time
  - Additional TMOR is being purchased at Time 15 even though there is no need for it at that time
  - Artificial operating reserve demand increases prices/load payments
- In general, this approach is not as efficient as buying the ‘right’ product at the ‘right’ time
Manual actions: In practice

• Neither of these manual actions is perfect
• How often are they used by ISO New England Operators?
Manual actions: In practice

• Preramping using the Manual DDP method
  – Manual DDPs may be issued for a variety of reasons
  – For preramping, only Manual DDPs for the ‘usual suspects’ are relevant

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (# of contiguous time blocks)</td>
<td>22</td>
<td>14</td>
</tr>
<tr>
<td>Average duration (min)</td>
<td>63.4</td>
<td>22.5</td>
</tr>
<tr>
<td>Median duration (min)</td>
<td>32.5</td>
<td>10</td>
</tr>
</tbody>
</table>
Manual actions: In practice

- Reserve Bias method

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (# of contiguous time blocks)</td>
<td>32</td>
<td>16</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Average duration (min)</td>
<td>89</td>
<td>71</td>
<td>99</td>
<td>125</td>
</tr>
<tr>
<td>Median duration (min)</td>
<td>85</td>
<td>52.5</td>
<td>77.5</td>
<td>125</td>
</tr>
<tr>
<td>Average bias (above original Operating Reserve requirement)</td>
<td>40.568%</td>
<td>33.026%</td>
<td>25.062%</td>
<td>6.063%</td>
</tr>
<tr>
<td>Median bias (above original Operating Reserve requirement)</td>
<td>34.153%</td>
<td>23.290%</td>
<td>14.607%</td>
<td>6.063%</td>
</tr>
</tbody>
</table>
Manual actions: Trends and explanations

• The Manual DDP method is being used less frequently and for shorter durations

• The Reserve Bias method is being used less frequently and with a lower biases

• Potential explanations
  – Decrease in natural gas prices
    – Faster combined cycle units are cheaper to run
    – Slower steam units run less frequently
  – New RT commitment software has a 4-hour time horizon so commitment decisions consider longer-term needs
  – Challenging ramping situations have been infrequent in recent years
Manual actions: Conclusions

• While the Manual DDP and Reserve Bias methods are imperfect, they result in better ramping behavior than the single-period dispatch problem.

• The rarity of manual actions makes them a poor motivation for market design changes per se.

• However, this assessment may change in the future due to greater renewable penetration (e.g., CAISO duck curve).
SOLUTION 2. MULTI-PERIOD DISPATCH
Disclaimer

• The ISO-specific descriptions of this section are based on the best of our knowledge

• We have endeavored to ensure the accuracy of all explanations and examples

• However, it is possible that this information may not match actual ISO implementations

• Any errors are solely the author’s responsibility
Motivation

• The NYISO generation fleet historically had a high prevalence of slow-ramping units*

• This fleet composition required preramping during periods of rapidly increasing load

* David Patton, Public Utility Commission of Texas Project No. 47199 Workshop (8/10/2017)
Current NYISO/CAISO practice

- NYISO solves a **multi-period** RT dispatch problem that covers approximately 1 hour
- CAISO also solves a **multi-period** RT dispatch problem
- These approaches are different from ISO-NE’s **single-period** RT dispatch problem

- A multi-period dispatch problem explicitly reflects forecasted changes (but not uncertainty) over its long look-ahead period
Current NYISO/CAISO practice

• How does this multi-period dispatch affect
  – Prices
  – Dispatch quantities
  – Total incremental cost
  – Total out-of-market payments
Multi-period dispatch: Pricing

• Recall that a single-period dispatch problem is associated with a single market-clearing price (assuming no transmission or losses)
  – Mathematical consequence of optimization

• From the same mathematics, a multi-period dispatch problem is associated with **multiple** market-clearing prices (one for each point of the time horizon)
Multi-period dispatch: Pricing

• LMP interpretation: “Redispatch cost” of satisfying the next MW of load for a given location and time
  – How much would the dispatch problem’s optimal production cost change due to the next MW of load at a given location and time?

• For a single-period problem, the only possible redispatch entails changing DDPs for the target time

• For a multi-period problem, the least expensive redispatch may entail simultaneously changing DDPs for multiple target times
  – LMPs from multi-period dispatch vary by (1) the price target time, and (2) when the price was calculated
  – These concepts will be shown with an example
Multi-period dispatch: Example

ISO simultaneously makes decisions for the entire multi-period horizon

Time 30 feasible regions depend on the Time 15 DDPs
Multi-period dispatch: Example

1. Time 0
   - 20 (TMOR)
   - 80 (DDP)
   - $60/MWh
   - +20MW
   - -30MW

2. Time 15
   - 23 (TMOR)
   - 77 (DDP)
   - $60/MWh
   - +23MW
   - -30MW

3. Time 30
   - 85 (DDP)
   - 15 (TMOR)
   - $60/MWh
   - +23MW

Load = 252MW
Op Res req = 55MW

Load = 280MW
Op Res req = 55MW

- No Operating Reserve violation at Time 30
Multi-period dispatch: Example

- Production cost (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 cost ($)</td>
<td>1,155</td>
<td>1,275</td>
</tr>
<tr>
<td>Unit 2 cost ($)</td>
<td>7,875</td>
<td>8,775</td>
</tr>
<tr>
<td>Op Res violation ($)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total cost ($)</td>
<td></td>
<td>19,080</td>
</tr>
</tbody>
</table>

- Single-period dispatch: $20,030 (with Operating Reserve violation)
- Manual DDP method: $19,530
- Reserve Bias method: $19,140

- Multi-period dispatch is economically efficient!
Multi-period dispatch: Example

- Time 15 LMP: How much would the optimal multi-period incremental cost change with 1MW more load at Time 15?

1: **Time 0**

- Load = 280MW
- Op Res req = 55MW

2: **Time 15**

- Load = 253MW
- Op Res req = 55MW

3: **Time 30**

- Load = 280MW
- Op Res req = 55MW

**Red dispatch**

- At Time 15, Unit 1 ↑ 1MW
- No change in Time 30 dispatch

- LMP calculated at **Time 0 for Time 15** is $60/MWh
Multi-period dispatch: Example

- Time 30 LMP: How much would the optimal multi-period incremental cost change with 1MW more load at Time 30?

1: Load = 281MW
   - Op Res req = 55MW
   - Time 0:
     - Load: 281MW
     - 20 (TMOR) $60/MWh
     - 80 (DDP)
   - Time 15:
     - Load: 281MW
     - 22 (TMOR) $60/MWh
     - 76 (DDP)
   - Time 30:
     - Load: 281MW
     - 85 (DDP)

2: Load = 252MW
   - Op Res req = 55MW
   - Time 0:
     - Load: 252MW
     - 40 (TMOR) $180/MWh
     - 170 (DDP)
   - Time 15:
     - Load: 252MW
     - 40 (TMOR) $180/MWh
     - 176 (DDP)
   - Time 30:
     - Load: 252MW
     - 40 (TMOR) $180/MWh
     - 196 (DDP)

Redispach:
- At Time 15, Unit 1 ↓ 1MW
- At Time 15, Unit 2 ↑ 1MW
- At Time 30, Unit 2 ↑ 1MW

What is the LMP calculated at Time 0 for Time 30?
= − 60 + 180 + 180
= $300/MWh
Multi-period dispatch: Example

- LMPs and RMCPs calculated at Time 0 are determined by the total redispatch cost for 1MW of incremental load/reserves in each of the target times
  - LMP for Time 15 = $60/MWh
  - LMP for Time 30 = $300/MWh
  - RMCP for Time 15 = $0/MWh
  - RMCP for Time 30 = $240/MWh

- Multi-period dispatch produces prices for each time interval in the multi-period horizon
Multi-period dispatch: Pricing

• Prices from multi-period problems are mathematically linked
• These prices provide dispatch-following incentives for the time horizon as a whole in the absence of “lumpiness” issues
Multi-period dispatch: Example

• With the provided quantities and prices,
  – Unit 1: Revenue = $8,430; Cost = $2,430; Profit = $6,000
  – Unit 2: Revenue = $19,650; Cost = $16,650; Profit = $3,000

• What is each unit’s maximum profit over the time horizon?
  – Prices are fixed
  – Each unit chooses its own dispatch quantities subject to its private constraints (e.g., ramping limits, EcoMax, etc.)
    – Unit 1: Max profit = $6,000
    – Unit 2: Max profit = $3,000

• Neither unit has an incentive to deviate from its multi-period instruction when faced with the specified prices
Multi-period dispatch: Example

• Load payments (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Energy ($)</th>
<th>TMOR ($)</th>
<th>Uplift ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>7,530</td>
<td>900</td>
<td>0</td>
<td>8,430</td>
</tr>
<tr>
<td>Unit 2</td>
<td>17,250</td>
<td>2,400</td>
<td>0</td>
<td>19,650</td>
</tr>
<tr>
<td>Total</td>
<td>24,780</td>
<td>3,300</td>
<td>0</td>
<td>28,080</td>
</tr>
</tbody>
</table>

• Dispatch-following incentives of LMPs and RMCPs (remember 15-minute periods)
  – Assume that units consider entire time horizon

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Unit 2</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
Multi-period dispatch: NYISO settlement

• NYISO obtains multiple market-clearing prices and quantities from its multi-period dispatch problem

• From each solution, NYISO posts two types of prices and quantities
  – “Binding”: First point in the time horizon, used for settlement
  – “Advisory”: Later points in the time horizon, not used for settlement

• As time rolls forward, advisory prices are replaced by binding prices from new multi-period dispatch problems
Multi-period dispatch: NYISO settlement

- Conceptually, a NYISO-type settlement is presented below
Multi-period dispatch: CAISO settlement

- CAISO only posts the binding price from its multi-period RT dispatch (advisory prices are produced but not posted)

Legend:
- Look-ahead period, price NOT DISTRIBUTED
- Look-ahead period, price USED for settlement

Graph showing the RT problem solved at various times:
- RT problem solved at Time 0
- RT problem solved at Time 10
- RT problem solved at Time 20
- RT problem solved at Time 30
- RT problem solved at Time 40
Multi-period dispatch: Settlement issues

• **Theory**: All of the prices calculated by the multi-period dispatch matter (important for dispatch-following incentives)

• **In practice**: Only the first-period (binding) prices are used in settlement, the future (advisory) prices are ignored

• The “only use first-period prices” principle is simple but problematic
  – It can under-compensate/over-compensate resources
  – It can undermine dispatch-following incentives
Multi-period dispatch: Settlement issues

• As time moves forward, earlier choices (e.g., costs) are fixed
• Each subsequent multi-period dispatch problem optimizes over a different set of possibilities
• New binding prices will likely be different from previous advisory LMPs *for the same target time*
• These differences tend to be systematic:

  Binding peak prices tend to be systematically **lower** than advisory peak prices (opposite for off-peak prices)
Multi-period dispatch: Example

- Consider expanding the existing example to 3 periods

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
<th>Time 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load (MW)</td>
<td>252</td>
<td>280</td>
<td>278</td>
</tr>
<tr>
<td>Operating Reserve requirement (MW)</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
</tbody>
</table>

- Assume that the ISO uses a 2-period dispatch problem
  - The binding Time 15 prices and advisory Time 30 prices (calculated at Time 0) were identified earlier
  - How will the rolling horizon affect the binding Time 30 prices (calculated at Time 15)?
Multi-period dispatch: Example

**Time 15**
- 23 (TMOR)
- 77 (DDP)

**Time 30**
- 100
- 195
- 100 (max)
- 170 (min)

**Time 45**
- 100 (max)
- 215 (max)
- 170 (min)

Load = 252MW
Op Res req = 55MW

Load = 280MW
Op Res req = 55MW

Load = 278MW
Op Res req = 55MW
Multi-period dispatch: Example

1. Time 15
   - 23 (TMOR)
   - 77 (DDP)

2. Time 30
   - $60/MWh
   - 15 (TMOR)
   - +23MW
   - -30MW
   - 85 (DDP)

3. Time 45
   - $60/MWh
   - 15 (TMOR)
   - +15MW
   - -30MW
   - 85 (DDP)

What are the binding LMPs and RMCPs for Time 30?

Load = 252MW
Op Res req = 55MW

Load = 280MW
Op Res req = 55MW

Load = 278MW
Op Res req = 55MW

$180/MWh

$60/MWh
Multi-period dispatch: Example

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
<th>Time 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispatch for Time 15, 30</td>
<td>LMP = $60/MWh</td>
<td>LMP = $300/MWh</td>
<td>_</td>
</tr>
<tr>
<td></td>
<td>RMCP = $0/MWh</td>
<td>RMCP = $240/MWh</td>
<td>_</td>
</tr>
<tr>
<td>Dispatch for Time 30, 45</td>
<td>_</td>
<td>LMP = $180/MWh</td>
<td>LMP = $180/MWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RMCP = $120/MWh</td>
<td>RMCP = $120/MWh</td>
</tr>
</tbody>
</table>

- LMP: Advisory $300/MWh → Binding $180/MWh
- RMCP: Advisory $240/MWh → Binding $120/MWh
- *Price depression* (binding relative to advisory) even though the Time 30 forecast was perfect!
- What does this imply for dispatch-following incentives? See slides 66 - 67
Multi-period dispatch: Example

Why are binding peak prices depressed for preramping up?

• For a multi-period dispatch problem, the LMP for Time $t$ is a function of the marginal unit’s cost at Time $t$ and redispach costs for other target times.

• In general, redispach costs for other target times are only incurred when DDPs for different target times are linked by a binding ramp constraint.
Multi-period dispatch: Example

- For our LMP calculation at Time 0 for Time 30 (Slide 64), Unit 2 has a binding ramp rate constraint between Time 15 and Time 30
  - Redispatch costs can be incurred

\[
\text{LMP calculated at Time 0 for Time 30} \\
\text{LMP}_{30} = \$300/\text{MWh} \\
\text{Redispatch cost for Time 1} = -60 + 180 = \$120/\text{MWh} \\
\text{Preramped unit incremental cost} = \$180/\text{MWh}
\]
Multi-period dispatch: Example

- For our LMP calculation at Time 15 for Time 30 (Slide 77), no ramp rates are binding between Time 30 and Time 45
  - Redispatch costs cannot be incurred

LMP calculated at Time 15 for Time 30

\[ \text{LMP}_{30} = \$180/MWh \]

Preramped unit marginal cost = \$180/MWh

No redispatch costs
Multi-period dispatch: Example

• Systematic *price inflation* when preramping down (i.e., the output of a slow, cheap unit is decreased early) can be explained in a similar manner
Multi-period dispatch: Pros

• Approach leads to more efficient solutions than either single-period dispatch or manual Operator actions
• Can help preserve ramping capabilities/avoid reserve violations
• Easy to understand
• The complete set of binding and advisory prices from a multi-period dispatch problem provide adequate dispatch-following incentives
Multi-period dispatch: Cons

- Current binding/advisory distinction (and associated settlement) introduces dispatch-following incentive problems
- More complex pricing logic: LMPs reflect the impact of an incremental demand on total time horizon costs
- Settlement rules incorporating advisory prices may be necessary to resolve dispatch-following incentive issues
- Uncertainty in net load forecasts may be difficult to address (more study needed)
- Complex software implementation
Multi-period dispatch: Conclusions

• Avoids the subjectivity of ISO New England’s manual actions
• Tends to produce a more efficient dispatch solution than single-period dispatch
• Pricing is more complex for participants
• Dispatch-following incentives can present issues depending on the settlement rules
SOLUTION 3. RAMP PRODUCTS
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Motivation

• MISO
  – Net load volatility was expected to increase due to an evolving resource mix
  – The inclusion of longer-term needs in MISO’s single-period dispatch problem could improve economic efficiency

• CAISO
  – Increasing penetration of renewable energy was identified as an operational challenge
  – Forecasted load changes were already handled by a multi-period dispatch problem (similar to NYISO), but uncertainty remained a concern

MISO. “Ramp Capability Product Cost Benefit Analysis” (6/2013)
CAISO. “Tariff Amendment to Implement Flexible Ramping Product” (6/24/2016)
Current MISO/CAISO practice

- MISO and CAISO introduced a single ramp-up/ramp-down product pair to their dispatch problems
- These products have their own prices and can impact LMPs

- Ramp product requirements explicitly reflect forecasted changes and uncertainty
Ramp product requirements

- Requirements based on forecast + uncertainty
  - MISO: 10 minutes post-DDP
  - (CAISO: 5 minutes post-DDP)
Ramp product designations (MISO)

• Timeframes for products and requirements must match
• Since ramp product requirements reflect changes 10 minutes post-DDP, ramp product designations must also reflect capabilities 10 minutes post-DDP
  – The actual implementation does not agree with this definition!
• Only online units can provide ramp products
Ramp product designations (MISO)

- MISO has the following ramp-down designation constraints in its dispatch problem
  
  \[
  \text{Ramp-down} \leq \text{DDP} - \text{RegMW} - (\text{EcoMin or RegLow}) \\
  \text{Ramp-down} \leq \text{RampRate} \times (\text{Scaling factor} / \text{Horizon})
  \]
Ramp product designations (MISO)

- MISO has the following ramp-up designation constraints in its dispatch problem:
  \[
  \text{Ramp-up} \leq (\text{EcoMax or RegHigh}) - \text{DDP} - \text{RegMW} - \text{TMSR} - \text{T MOR} \\
  \text{Ramp-up} \leq \text{RampRate} \times (\text{Scaling factor} / \text{Horizon})
  \]
Ramp product designations (MISO)

• How do reserves affect ramp-up designations?
  – No MW can be counted as both reserves and ramp-up
  – Ramp-up has lower penalty price → reserves favored by dispatch

• Consider ramp products and TMSR
Ramp product designations (MISO)

- Consider ramp products, TMSR, and TMOR

- Do these ramp product designations make sense?
Current MISO/CAISO practice

• How do ramp products affect
  – Prices
  – Dispatch quantities
  – Total incremental cost
  – Total out-of-market payments
Ramp product method: Example

• Only ramp-up products and requirements will be considered

• Assuming a 15-minute ramp product horizon, the ramp-up requirement is 28MW (= 280MW – 252MW)

• Ramp penalty price = $100/MWh
  – MISO’s ramp penalty price is $5/MWh
  – CAISO’s ramp penalty price is $60/MWh
Ramp product method: Example

**Time 0**
- 20 (TMOR)
- 80 (DDP)
- +20MW
- -30MW

**Time 15**
- 20 (TMOR)
- 100
- 50

**1:**
- 40 (TMOR)
- +20MW
- 170 (DDP)
- -0MW

**2:**
- 190
- 170

Load = 252MW
Op Res req = 55MW
Ramp-up req = 28MW
Ramp product method: Example

1: Time 0
- 80 (DDP)
- 20 (TMOR)
- 15 (TMOR) +20MW
- 3 (Ramp) -30MW

2: Time 15
- 82 (DDP)
- 80 (DDP)
- 170 (DDP)
- 40 (TMOR)
- 40 (TMOR)
- 170 (DDP)

• Outputs are the same as the single-period dispatch solution
• Ramp violation of 5MW at Time 15
Ramp product method: Example

Prices for Time 15

• The LMP, RMCP, and ramp price (RampCP) are determined by the marginal cost of serving energy, reserves, and ramp, respectively
  – LMP = $160/MWh (Unit 1 ↑ 1MW, Ramp violation ↑ 1MW)
  – RMCP = $100/MWh (Ramp violation ↑ 1MW)
  – RampCP = $100/MWh (Ramp violation ↑ 1MW)

• Assume that uplift is calculated for each dispatch interval separately
  – Neither unit requires uplift
Ramp product method: Example

1: Time 0
- 20 (TMOR)
- 80 (DDP)

Time 15
- 15 (TMOR)
- 82 (DDP)

Time 30
- 100

- 3 (Ramp)
- 52

- $60/MWh
- +18MW

- $180/MWh

2: Time 0
- 40 (TMOR)
- 170 (DDP)

Time 15
- 20 (Ramp)
- 40 (TMOR)

Time 30
- 190

- 20 (Ramp)
- 170

- $180/MWh
- +20MW

- 170 (DDP)

- 170 (DDP)

- Load = 252MW
- Op Res req = 55MW
- Ramp-up req = 28MW

- Load = 280MW
- Op Res req = 55MW

- Time 30 ramp-up requirement not needed
Ramp product method: Example

1. **Time 0**
   - Load = 280MW
   - Op Res req = 55MW
   - Ramp-up req = 28MW

2. **Time 15**
   - Load = 252MW
   - Op Res req = 55MW
   - Ramp-up req = 28MW

3. **Time 30**
   - Load = 252MW
   - Op Res req = 55MW
   - Ramp-up req = 28MW

- The system must sacrifice reserve to preserve the energy balance.
- Operating Reserve violation of **5MW** at Time 30.
Ramp product method: Example

Prices for Time 30

• The LMP and RMCP are determined by the marginal cost of servings energy and reserves, respectively
  – LMP = $1,060/MWh (Unit 1 ↑ 1MW, Res violation ↑ 1MW)
  – RMCP = $1,000/MWh (Res violation ↑ 1MW)

• Assume that uplift is calculated for each dispatch interval separately
  – Neither unit requires uplift
Ramp product method: Example

- Production cost (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1 cost ($)</td>
<td>1,230</td>
<td>1,350</td>
</tr>
<tr>
<td>Unit 2 cost ($)</td>
<td>7,650</td>
<td>8,550</td>
</tr>
<tr>
<td>Op Res violation ($)</td>
<td>0</td>
<td>1,250</td>
</tr>
<tr>
<td>Ramp-up violation ($)</td>
<td>125</td>
<td>–</td>
</tr>
<tr>
<td>Total cost ($)</td>
<td>20,155</td>
<td></td>
</tr>
</tbody>
</table>

- Single-period dispatch: $20,030 (with Operating Reserve violation)
- Manual DDP method: $19,530
- Reserve Bias method: $19,140
- Multi-period dispatch: $19,080
Ramp product method: Example

- Load payments (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Energy ($)</th>
<th>TMOR ($)</th>
<th>Ramp-up ($)</th>
<th>Uplift ($)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>27,130</td>
<td>2,875</td>
<td>75</td>
<td>0</td>
<td>30,080</td>
</tr>
<tr>
<td>Unit 2</td>
<td>57,150</td>
<td>11,000</td>
<td>500</td>
<td>0</td>
<td>68,650</td>
</tr>
<tr>
<td>Total</td>
<td>84,280</td>
<td>13,875</td>
<td>575</td>
<td>0</td>
<td>98,730</td>
</tr>
</tbody>
</table>

- Dispatch-following incentives of LMPs and RMCPs (remember 15-minute periods)

<table>
<thead>
<tr>
<th></th>
<th>Time 15</th>
<th>Time 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Unit 2</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
Ramp product method: Example summary

• The ramp product approach is more efficient than single-period dispatch
• It is less efficient than multi-period dispatch
• The ramp product approach does not avoid the reserve violation at Time 30
• The ramp product avoids uplift payments in this example
Ramp product method: Issues

• The ramp products implemented by MISO and CAISO have major drawbacks

The following slides are the most important part of this presentation!
Ramp product method: Issue 1

What are the consequences of ramp-reserve interactions?

- Assume that the unit is not assigned TMOR
- Ramp product definition
  - Ramping capability 10 minutes post-DDP
- Is the ramp product definition reflected to the right?
  - No
Ramp product method: Issue 1

What are the consequences of ramp-reserve interactions?

- Output 10 minutes post-DDP should be capped by
  \[ \text{DDP} + 10 \times \text{RampRate} \]

- The designations to the right imply that \( \text{DDP} + 20 \times \text{RampRate} \) is possible

![Diagram showing EcoMax, TMSR, DDP, and EcoMin with Ramp-up designation]
Ramp product method: Issue 1

What are the consequences of ramp-reserve interactions?

• Ramp-up designations can also be artificially capped by EcoMax
Ramp product method: Issue 1

Conclusion

• The ramp-up product implementation doesn’t correspond to its definition
  – “Ramping capability post-DDP” overlaps with reserve definition
Ramp product method: Issue 2

Ignoring reserves, are there other ramp product designation problems?

- Designations are based on the unit’s ramp rate at DDP

Ramp-up logic does not “see” this 1MW/min ramp rate
Ramp product method: Issue 2

Conclusion

• MW-dependent ramp rates can lead to inaccurate ramp product designations
Ramp product method: Issue 3

Does a ramp product implementation represent a “permanent” flexibility solution?

- Ramp products enforce requirements for their respective target times
  - MISO: 10 minutes post-DDP
  - CAISO: 5 minutes post-DDP

- A single target time was adequate for MISO and CAISO, but additional target times (i.e., ramp products) may be necessary as system conditions change
  - For example, if new multi-hour ramping needs emerge
Ramp product method: Issue 3

Conclusion

• Ramp product horizons may need to be longer than currently implemented for ISOs/RTOs with sustained, multi-hour ramping needs

• Additional ramp products/horizons may be needed in the future
  – More work for the ISOs/RTOs and their participants 😞
Ramp product method: Issue 4

Assuming “correct” forecasted change + uncertainty, do ramp product requirements guarantee feasibility (no violations)?

- MISO: No
Ramp product method: Issue 4

Assuming “correct” forecasted change + uncertainty, do ramp product requirements guarantee feasibility (no violations)?

- MISO: No
Ramp product method: Issue 4

Assuming “correct” forecasted change + uncertainty, do ramp product requirements guarantee feasibility (no violations)?

- CAISO: Yes
Ramp product method: Issue 4

Assuming “correct” forecasted change + uncertainty, do ramp product requirements guarantee feasibility (no violations)?

- CAISO: Yes
Ramp product method: Issue 4

Conclusion

• To guarantee feasibility, the shortest ramp product horizon must equal the ISO’s dispatch frequency
  — If not, times will not “match up” and infeasibilities may not be avoided
Ramp product method: Issue 5

Are ramp products economically efficient?

- Ramp product requirements enforce feasibility, not optimality
- The future cost of “deploying” ramp products is not considered when clearing them
  - The feasible solution identified by the ramp product implementation may be expensive

Conclusion

- Ramp product approaches are generally not as efficient as a multi-period dispatch solution
Ramp product method: Issue 6

How should ramp penalty prices be determined?

- The necessary ramp penalty price is highly dependent on system conditions and unit offers
  - MISO’s ramp penalty price is $5/MWh
  - CAISO’s ramp penalty price is $60/MWh
  - In the earlier example, a penalty of $100/MWh did not successfully avoid a reserve violation

Conclusion

- It is difficult to establish defendable ramp penalty prices without extensive testing and simulation
Ramp product method: In practice

• There are obviously some issues with the implemented ramp product design

• What are the monetary consequences?
Ramp product method: In practice (MISO)

- RT market comparison (7/2016)
  - Average LMP decreased from $30.05/MWh to $29.81/MWh
  - LMP standard deviation decreased by 7%
  - Production cost decreased by $400,000
  - Reserve shortage costs decreased by 16.8%

MISO. “Ramp Capability Product Performance Update” (11/29/2016)
Ramp product method: In practice (MISO)

• Ramp pricing summary (5/1/2016 – 9/30/2016)
  – Average DA ramp-up price = $0.55/MWh
  – Average RT ramp-up price = $0.13/MWh
  – Average DA ramp-down price = $0/MWh (never binding)
  – Average RT ramp-down price = $0/MWh (never binding)

• Total ramp product payments (5/1/2016 – 9/30/2016)
  – DA: $1.31 million
  – RT: $35,000
  – Annualized ramp product payments = ~$3-4 million
    • MISO 2016 market size = $24.7 billion
    • (ISO New England 2016 market size = $7.6 billion)

Ramp product method: Pros

- Can help preserve ramping capabilities/avoid reserve violations
- Explicit market price for ramping capability
- Requirements can incorporate uncertainty in net load over the ramp product time horizon
Ramp product method: Cons

• Unclear incentives from ramp product prices
  – Prices/payments are based on the product implementation, which does not match the product definition

• Number and horizon of ramp products is highly dependent on system conditions → needs may change over time

• Ramp products cannot ensure feasibility (e.g., prevent reserve violations that are avoidable with other approaches)

• Ramp products cannot ensure optimality
  – Less efficient than multi-period dispatch
Ramp product method: Conclusions

• Ramp products are an interesting idea but current implementations leave much to be desired
• There is no widely accepted way to determine ramp requirement penalty factors or when/if ramp products are needed
• The approach is not as efficient as multi-period dispatch but may be easier to implement for ISOs/RTOs currently using single-period dispatch
KEY TAKEAWAYS
Key takeaways

• All of the current approaches are imperfect in different ways
• The next session will discuss other approaches for ramp capability procurement and reimbursement
• It is unclear whether the historical frequency of ramping problems (necessitating manual actions) is serious enough to warrant major market changes
• System ramping challenges depend on the resource mix and could become more significant with greater renewable penetration