Price Formation Education 3: Reserves and Co-optimization

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This is not a committee meeting.

- This session is for educational purposes only, to help introduce and clarify different aspects of price formation.
- The material presented is not necessarily representative of any proposal PJM has or will present in the future.
Agenda

Recap of Session 1 and 2

Review of different reserve products
  • Day-Ahead Scheduling Reserve
  • Synchronized Reserve
  • Non-Synchronized Reserve

Joint Optimization of Energy and Reserves

How other ISO/RTOs Handle Reserves
Session 1
Economic Dispatch Basics

Videos are available here
PJM.com > Committees & Groups > Stakeholder Meetings > Price Formation Education Sessions

Recap of Session 1

Unit Commitment → Economic Dispatch → Locational Prices

- Start-up cost ($/start)
- Incremental energy cost ($/MWh)
- No-load cost ($/hour)

We assume no startup or no-load cost. Each resource is completely flexible.

PJM CAISO ISO-NE MISO NYISO
Separate Pricing and Dispatch Runs
Economic Minimum Relaxation
Includes Startup and No-Load Costs

What happens if we introduce inflexibility to the resources?

Minimum output the resource can produce when online
Available Minimum Output
Recap of Session 2

Session 2
Alternative Pricing Frameworks

Videos are available here
PJM.com > Committees & Groups > Stakeholder Meetings > Price Formation Education Sessions

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The purpose of this session is to ensure all stakeholders have a sufficient understanding of how reserve products and markets operate in PJM and other RTOs/ISOs.
RESERVES

Overview
Reserves are additional generation capacity above the expected load. Scheduling excess capacity protects the power system against potential operating events, such as loss of energy or load forecasting errors.

What Are Reserves?

OPERATING RESERVE
Power that can be received within 30 minutes

PRIMARY
Power received within 10 minutes

SUPPLEMENTAL
Power received within 10 to 30 minutes

Shortage Pricing Focus
Why Procure Reserves?

- The main function of reserve resources is to recover the power balance and frequency balance within 10 minutes.
- These resources provide a quick boost of generation (or load reduction) to the system to recover balance after resource loss, after large network tie errors and in under-frequency conditions.
  - Note: Synchronous Reserves cannot control over-frequency.
Single reserve zone with a sub-zone: Mid-Atlantic Dominion (MAD)
Exists due to potential reserve deliverability issues

- The sub-zone is defined based on the most-limiting transfer interface.
- Resources with 3 percent or greater raise-help distribution factor on the interface are included in the MAD sub-zone.
**Scheduling and Operating Reserves**

**DAY-AHEAD SCHEDULING RESERVES**
- Power received within 30 minutes
- Cleared in Day-Ahead Market
- Not maintained in real time

**PRIMARY**
- Power received within 10 minutes
- Cleared in Real-Time Reserves Market
- Maintained in real time

**SUPPLEMENTAL**
- Power received within 10 to 30 minutes
- Currently no market
- Maintained in real time
DAY-AHEAD SCHEDULING RESERVES

Overview
Day-Ahead Scheduling Reserve (DASR) Market Overview

Offer-based market for 30-minute reserve, which can be provided by both offline and online generation and demand response resources.


Purpose: Incent generation and demand response resources to provide the flexible capability to provide 30-minute reserves.

Designed to clear existing DASR requirements as defined by reliability standards (RFC and SERC).

Costs of base DASR will be allocated by real-time load-ratio share. Costs of additional DASR will be allocated to net purchaser in real time.
Note: In response to a Hot or Cold Weather Alert or other conservative operations, additional megawatts are added to the base DASR requirement.
A resource will be considered eligible to provide DASR if it...:

- Is electrically located within PJM
- Is available to provide reserves
- Can reliably provide DASR obligations in real time
- Is not synchronized to the grid but has start-up plus notification time of less than or equal to 30 minutes
- Is synchronized to the grid and has additional capacity available
DASR Example 120 MW Load

- **DASR**
  - **15 MW**
  - **LMP**: $15/MWh
  - **DASRCP**: $0/MWh

- **$10 Energy Offer**
  - $0/MWh offer

- **$15 Energy Offer**
  - $0/MWh offer

- **$17 Energy Offer**
  - $5/MWh offer

- **$40 Energy Offer**
  - $1/MWh offer

- **$0 sets clearing for DASR**

The chart shows a $10 energy offer at $0/MWh, $15 energy offer at $0/MWh, $17 energy offer at $5/MWh, and a $40 energy offer at $1/MWh. The DASR example includes 15 MW with an LMP of $15/MWh and a DASRCP of $0/MWh. The chart illustrates the clearing of DASR for different energy offers.
DASR Example 140 MW Load

- **$10 Energy Offer**
  - $0/MWh offer
  - DASR: 15 MW
  - LMP: $16/MWh
  - DASRCP: $1/MWh

- **$15 Energy Offer**
  - $0/MWh offer
  - DASR: 15 MW
  - LMP: $16/MWh
  - DASRCP: $1/MWh

- **$17 Energy Offer**
  - $5/MWh offer
  - DASR: 15 MW
  - LMP: $16/MWh
  - DASRCP: $1/MWh

- **$40 Energy Offer**
  - $1/MWh offer
  - DASR: 15 MW
  - LMP: $16/MWh
  - DASRCP: $1/MWh

Legend:
- Cleared for DASR
- Available MW
- Dispatched MW
- Marginal for energy LMP

Provided for informational purposes only
• The DASR Market Clearing price represents the cost to serve an additional MW of DASR in the RTO.

• Energy and DASR are jointly co-optimized.
  – DASR clearing is based on DASR offer and lost opportunity cost (LOC).
  – LOC is the forgone profit in energy market for providing reserve.
• Penalty = forgone revenue

• In order to be eligible for DASR revenue:
  – **Resources with start time plus notification time of > 30 minutes:** required to be online and operating at PJM’s direction during the hour of award with real-time dispatchable range at least as great as day-ahead dispatchable range
  – **Resources with start time plus notification time of ≤ 30 minutes:** required to be available to the PJM operators for dispatch during the hours of the award and to start within 30 minutes if dispatched by PJM
SYNCHRONIZED RESERVES

Overview
Reserve Services
Each service carries a reserve requirement.

Primary Reserve

Synchronized Reserve
- Tier 1 Resources
- Tier 2 Resources

Non-Synchronized Reserve (NSR)
- NSR Resources

Reserve Products
Each product has a clearing price.
The Synchronized Reserve Requirement:
- Is the amount of 10-minute reserves that must be synchronized to the grid
- May only be met with online resources

RTO reserve zone requirement is the greater of:
- Calculated RFC minimum requirement or
- Largest contingency in RTO Synchronized Reserve zone
  - Dynamically calculated based on the current output of the largest contingency

MAD sub-zone requirement is equal to the largest contingency in the MAD region.
Synchronized Reserve Requirement

Reliability Requirement + 190 MW Adder (permanent) + Additional Scheduled Reserves (optional) = Synchronized Reserve Requirement

- Largest output of online unit
- MAD SR deficit mean + 1 standard deviation
- Additional MWs called on for reliability concerns

Note: At times, an outage condition at a station whereby a single fault would trip multiple generators resulting in a loss of generation greater than the largest single generator, PJM will carry an increased reserve requirement in equivalent summation of output of those multiple generators. This summation will be reflected in the reliability requirement.
A resource will be considered eligible to provide Synchronized Reserve if it...

- Is electrically located within the PJM RTO
- Is available to provide reserves
- Is electrically synchronized to the grid
- Can provide energy (or reduce load) within 10 minutes of notification from PJM dispatch
- Has not designated its entire output as emergency
- Is able to respond for 30 minutes
<table>
<thead>
<tr>
<th>Tier 1 (Economic)</th>
<th>Online units that are following economic dispatch and are only partially loaded, and therefore are able to increase output within 10 minutes following PJM dispatcher request</th>
</tr>
</thead>
</table>
| Tier 2 (Non-Economic) | Resources that have offered into the Synchronized Reserve Market and cleared  
  - Condensers (CTs and hydro) transition to online Tier 2 condense mode  
  - CTs online at min – operating at a point that deviates from economic dispatch  
  - Steam reduced to provide Tier 2 MW  
  - Demand response that can drop load |
| 10 Minute Non-Synchronized Reserve | Resources currently not synchronized to the grid  
  - Shutdown run-of-river hydro  
  - Shutdown pumped hydro  
  - Offline industrial combustion turbines, jet engine/expander turbines, etc. |
Tier 1 Capability Calculation – Example

10 Min. Ramp Point (380 MW)

Synchronized Reserve Maximum (400 MW)

Total Remaining Capacity = 100 MW
Ramp Capability = 80 MW
Estimated Dispatch Point (300 MW)

Synchronized Ramp Rate = 8 MW/min
Therefore Max T1 Capability = 8 MW/min * 10 min = 80 MW
Ramp Rate is more limiting, so T1 capability = 80 MW
Resources With No Tier 1 Estimate

Tier 1 is not estimated for:

• Demand response
• Resources where EcoMin = EcoMax and no SpinMax data
• Combined cycle units operating in the duct-burner range
• Resources that are normally non-reserve: wind, solar, nuclear, etc.
Tier 2 – Flexible vs. Inflexible Resources

**Flexible**

**Resources**
- Online generators following economic dispatch that can be backed down for Tier 2
- Tier 2 DSR that opt to be flexible

**Attributes**
- Can respond immediately to real-time five-minute commitment
- Has ability to receive Tier 2 commitment via approved telemetry

**Inflexible**

**Resources**
- Synchronous condensers that can be committed for Tier 2 from offline state
- Other Tier 2 DSR

**Have limiting parameters, such as:**
- Minimum run time of one hour
- Notification/lead time of at least 30 minutes

Tier 2 commitment notification is through Markets Gateway
Synchronized Reserve Market Timeline

10:30 a.m.

Due a day ahead of the operating day, by 10:30 a.m.
- Energy schedule for LOC calculation to qualified units

2:15 p.m.

Due a day ahead, by 2:15 p.m.
Tier 2 Offer Price (capped at actual cost + $7.50/MWh adder)
- All other SR data can be revised up to 65 minutes before the operating hour.

6:30 p.m.

Up to 65 min prior to the operating hour
- SR status (Available, Unavailable)
- Offer MW
- Offer Price*
- Self-Scheduled MW
- Spin Max
*subject to intraday offer rules

Data submitted to Markets Gateway

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NON-SYNCHRONIZED RESERVES

Overview
Primary Reserve

Synchronized Reserve
- Tier 1 Resources
- Tier 2 Resources

Non-Synchronized Reserve (NSR)
- NSR Resources

Reserve Products
Each product has a clearing price.
The Primary Reserve Requirement:
- The amount of 10-minute reserve (synchronized or offline) that must be available
  - Including the Synchronized Reserve requirement
- May be met with online and offline resources

RTO reserve zone requirement is the greater of:
- Calculated RFC minimum requirement or
- 150% of the largest contingency in the PJM footprint
  - Dynamically calculated every five minutes

MAD sub-zone requirement is equal to 150% of the largest contingency in MAD region
- Any reserves committed in the MAD sub-zone will be used to meet the 503 MW VACAR Reserve Sharing Group commitment.
Primary Reserve Requirement

PR Reliability Requirement

SR Reliability Requirement * 150%

190 MW Adder (permanent)

Same as SR adder

Additional Scheduled Reserves (optional)

Same amount as SR additional MWs

Primary Reserve Requirement

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Non-Synchronized Reserve (NSR) Participation

A resource will be considered eligible to provide NSR if it:

- Is electrically located within the PJM RTO
- Is available to provide reserves
- Is not electrically synchronized to the grid
- Can provide energy within 10 minutes of notification from PJM dispatch
- Has not designated its entire output as emergency
- Is able to sustain output for 30 minutes

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CLEARING AND PRICING

Overview
Product Substitution

When MWs from a single product can be used to meet the requirements for multiple products:

Synchronized Reserves

- Requirement: 1,450 MW
- Available: 2,000 MW
- Cleared: 1,450 MW
- Remaining: 550 MW

Primary Reserves

- Requirement: 2,175 MW
- SR: -1,450 MW
- 725 MW

Cleared based on most economic set

Note: Since Synchronized Reserves can be used to meet the Primary Reserve requirements, the SR clearing price must be at least as great as the NSR clearing price.

SR Price >= NSR Price
When MWs from one location are used to meet the requirements for multiple locations.

**MAD Synch Reserves**

**RTO Synch Reserves**

**Locational Substitution**

**RTO zone**

**MAD sub-zone**

Requirement 1,500 MW
MAD -1,450 MW
50 MW

Available: 1,600 MW
Cleared: 1,450 MW
Remaining: 150 MW

Note: Since reserves in MAD can be used to meet the RTO reserve requirement, the MAD clearing price must be at least as great as the RTO clearing price.

MAD Price >= RTO Price
Relationship Between Reserve Products and Locations

MAD Synch Reserves
MW can be used to meet MAD PR requirement or RTO SR requirement.

RTO Synch Reserves
MW can be used to meet RTO PR requirement.

MAD Primary Reserves
MW can be used to meet RTO PR requirement.

RTO Primary Reserves

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### Market-Clearing Engines

**ASO**

Ancillary Services Optimizer

- **1 Hour Ahead**
- Primary Objective: commit inflexible resources based on hour-ahead forecast

**ITSCED**

Intermediate Term Security Constrained Economic Dispatch

- **30 Minutes Ahead**
- Primary Objective: Recommend additional inflexible resources if needed

**RTSCED**

Real-Time Security Constrained Economic Dispatch

- **10 Minutes Ahead**
- Primary Objective: Commit flexible resources to meet the balance of the requirement; calculate SRMCPs
Real-Time Market Clearing Engines & Reserve Pricing

ASO

1 Hour Ahead

- ASO clears to the requirement but **only** commits inflexible resources.
- Tier 1 estimate is based on hour look-ahead forecast.
- Tier 2 resources (inflexible and flexible) are cleared based on most economic set.
  - Only inflexible resources receive a firm commitment.
- No clearing price is calculated in ASO.

Requirement = 1,450 MW
Real-Time Market Clearing Engines & Reserve Pricing

ITSCED

30 Minutes Ahead

- ITSCED clears to the requirement and considers the inflexible Tier 2 already committed by ASO.
- Tier 1 estimate is updated based on look ahead forecast.
- Tier 2 resources (inflexible and flexible) are cleared based on most economic set.
- Additional Tier 2 inflexible resources are recommended by ITSCED but do not receive a firm commitment unless manually called on by Dispatch.
- No clearing price is calculated in ITSCED.

Requirement = 1,450 MW
Real-Time Market Clearing Engines & Reserve Pricing

- RTSCED clears to the requirement and considers any inflexible Tier 2 already committed by ASO or ITSCED.

- Tier 1 estimate is updated based on current system conditions.

- Tier 2 flexible resources are committed to meet the balance of the requirement.
  - If there is sufficient Tier 1 to meet the requirement, no flexible Tier 2 is committed and the SRMCP is zero.
  - If additional flexible Tier 2 must be committed, the SRMCP is non-zero.
Marginal Cost Pricing in the Reserve Markets

- Inflexible resources are treated as block loaded in RTSCED and cannot set marginal price.
- Flexible resources set the market clearing price for reserves.
  - Non-zero SRMCPs are generated only when flexible resources are committed by RTSCED.
- If SRMCP is zero, any inflexible resources are paid through uplift (make-whole payments).
- The challenges are similar to those of inflexible resources being priced for energy.

### Table 10–19
RTO Zone, Mid-Atlantic Subzone tier 2 synchronized reserve MW, credits, weighted price, and cost (including self scheduled): January 1 through September 30, 2017

<table>
<thead>
<tr>
<th>Zone</th>
<th>Year</th>
<th>Month</th>
<th>Tier 2 Credited MW</th>
<th>Tier 2 Credits</th>
<th>Weighted Average Synchronized Reserve Market Clearing Price</th>
<th>Tier 2 Synchronized Reserve Cost</th>
<th>Price/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAD Subzone</td>
<td>2017</td>
<td></td>
<td>1,506,814</td>
<td>$17,808,590</td>
<td>$3.98</td>
<td>$12.22</td>
<td>32.6%</td>
</tr>
<tr>
<td>RTO Zone</td>
<td>2017</td>
<td></td>
<td>3,569,981</td>
<td>$29,709,256</td>
<td>$3.14</td>
<td>$8.32</td>
<td>34.5%</td>
</tr>
</tbody>
</table>

Source: Monitoring Analytics, LLC “State of the Market Report for PJM, January through September 2017”
Non-Synchronized Reserve Market Clearing Price

- The Non-Synchronized Reserve Market Clearing Price (NSRMCP) represents the cost to serve an additional MW of Primary Reserves in the RTO or MAD reserve zone.
- NSRMCP is calculated based on (either)
  - SRMCP when extra flexible Tier 2 is used to satisfy the Primary Reserve requirement
  - LOC from revenue forgone from not providing energy and staying offline
### Example 1 – NSR with no LOC used to meet remainder of PR requirement

<table>
<thead>
<tr>
<th>Resource</th>
<th>Status</th>
<th>Offer (MW)</th>
<th>Offer ($)</th>
<th>LOC ($)</th>
<th>Effective Cost ($) (LOC + Offer)</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Online</td>
<td>10</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>10 MW SR</td>
</tr>
<tr>
<td>B</td>
<td>Online</td>
<td>10</td>
<td>7.5</td>
<td>5</td>
<td>12.5</td>
<td></td>
</tr>
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<td>Offline</td>
<td>10</td>
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<td>12</td>
<td>12</td>
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<td>0</td>
<td>15</td>
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<tr>
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<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>G</td>
<td>Online</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>SR Requirement</th>
<th>20</th>
<th>PR Requirement</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRMCP</td>
<td>$6</td>
<td>NSRMCP</td>
<td>$0</td>
</tr>
</tbody>
</table>
Example 2 – NSR with LOC used to meet remainder of PR requirement

<table>
<thead>
<tr>
<th>Resource</th>
<th>Status</th>
<th>Offer (MW)</th>
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</table>

SR Requirement 20  | PR Requirement 30
SRMCP $6           | NSRMCP $5
### Example 3 – Additional SR committed to meet PR requirement

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<th>Resource</th>
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Unit G sets the SRMCP and NSRMCP
Tier 1 Compensation

Tier 1 Credits are calculated based on MWh * Price

Was there a Synch Event?

Yes

NSRMCP > $0

MWh: Min (Tier 1 Actual, Tier 1 Estimate)
Price: SRMCP

NSRMCP = $0

MWh: Tier 1 Actual
Price: Premium Price (calculated using LMP during event)

No

NSRMCP > $0

MWh: Tier 1 Estimate
Price: SRMCP

NSRMCP = $0

MWh: N/A
Price: N/A
• Self-scheduled Synchronized Reserve resources are paid for the self-scheduled MW (less any shortfall due to failure to perform during a SR event).

\[
\text{Tier 2 SR Credits} = \text{Tier 2 SRMCP} \times (\text{Self Scheduled MW} \ – \ \text{Shortfall MW})
\]

• Pool-scheduled Synchronized Reserve resources are paid for the assigned MW (less any shortfall due to failure to perform during a SR event) and are made whole if the SRMCP does not cover their offer.

\[
\text{Tier 2 SR Credits} = \max(\text{Tier 2 SRMCP, SR Offer Price}) \times (\text{Assigned MW} \ – \ \text{Shortfall MW})
\]
Tier 2 Penalty for Non-Performance

- Compliance is measured only for Synchronized Reserve Events with a duration of 10 minutes or more.
- Resource is credited for Tier 2 in the amount responded for all hours it was assigned or self-scheduled on the day event occurred.
- Owner of the resource incurs a retroactive obligation to refund at the applicable SRMCP:
  - Amount of shortfall measured in MW
  - All hours the resource was assigned or self-scheduled over immediate past interval
  - Duration determined as lesser of average number of days between events or number of days since last non-performance
- Aggregate response can be used to offset retroactive obligation

Detailed description in section 4.2.12 of M-11 and section 6.3 of M-28
Non-Synchronized Reserve Compensation

- Resources that are assigned non-synchronized reserve are paid for the assigned MW at the cost of the marginal primary reserve resource.

\[ \text{NSR Credits} = \text{NSRMCP} \times (\text{NSR MW}) \]

- The NSRMCP will always be less than or equal to the SRMCP in the same location.
Who must acquire Synchronized/Non-Synchronized Reserves?

- All load serving entities (LSEs) must acquire Synchronized/Non-Synchronized Reserves.
- Obligation is determined from real time load ratio share.
- Obligation is by reserve zone.

Obligation can be satisfied by

- Self-supply from LSE’s own resources
- Entering into bilateral transactions with other participants
- Purchasing from PJM Synchronized/Non-Synchronized Reserve Markets
  - Loads located in the MAD sub-zone will pay the MAD SRMCP/NSRMCP.
  - Loads located outside the MAD sub-zone will pay the RTO SRMCP/NSRMCP.
JOINT OPTIMIZATION OF ENERGY AND RESERVES

Overview
Sequential optimization means separate dispatch solutions based on different expectations of system conditions are produced for ancillary services and energy.

- Prior to the implementation of Shortage Pricing, energy and reserves were cleared using sequential optimization.
  - The impact of reserve commitments on the energy dispatch was pre-determined.

- Reserve commitments were made on a forward basis and locked in based on an expectation of system conditions and could not be altered by the dispatch algorithm as system economics and reserve needs changed in real time.
Shortcomings of Sequential Optimization

- The power system in general changes too frequently to model accurately an hour in advance.
- Hour-ahead expectations that do not align with actual operating conditions resulted in:
  - A reserve clearing price that did not match the true cost of the product
  - A reserve resource set that was potentially not the most economical
  - An energy resource set that was potentially not the most economical
  - Out of market make-whole payments
• Regardless of methodology, reserves and energy come from the same supply pool.

• Allocating portions of the supply pool to each requirement will, at times, impact the marginal clearing price of both.

• In general, allocating resources to energy and reserves must be done to minimize the impacts of one product on the other in order to globally minimize the cost of both.

• If allocating resources to energy and reserves is done sub-optimally, the impacts of one product on another will be overstated.
The best method to allocate reserves and energy is to jointly optimize them in real-time.

- **Algorithmically**, this adds reserve requirements and commitments into the real-time and look-ahead dispatch algorithms.
- **Operationally**, this results in a more optimal energy dispatch and reserve commitment.
- **Economically**, this results in the lowest-cost solution.
Market Clearing, Dispatching and Pricing Engines

Ancillary Services Optimizer (ASO)
Clearing and assignment of regulation and inflexible reserve resources
(Solved 60 minutes prior to target time, looks ahead 60 minutes beyond target time)

Intermediate-Term Security Constrained Economic Dispatch (IT SCED)
Demand Trajectory, generator loading strategy, Demand Response commitment for energy, CT commitment and inflexible synchronized reserve recommendations (Solved 30 minutes prior to target time, looks ahead 15, 30, 75 and 120 minutes beyond target time)

Real-Time Security Constrained Economic Dispatch (RT SCED)
Final dispatch contour and assignment of non-synchronized reserve and flexible synchronized reserve resources (Solved 15 minutes prior to target time, looks ahead 15 minutes beyond target time)

Locational Pricing Calculator (LPC)
5 minute energy and ancillary service prices
Joint Optimization and IT/RT SCED Interaction

• Joint optimization better optimizes reserve commitments over the short and long term.

• The real-time dispatch can reallocate reserves on dispatchable units as economically as possible in real time to minimize cost.

• Forecasting tools can look over the longer term to see whether maintaining reserves on dispatchable resources is economic or whether CTs or demand response should be called on.
## Generator: Oakmont

<table>
<thead>
<tr>
<th>Economic Max</th>
<th>300 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 2 MW</td>
<td>50 MW</td>
</tr>
<tr>
<td>Offer Curve</td>
<td>$20 @ 100 MW</td>
</tr>
<tr>
<td></td>
<td>$40 @ 300 MW</td>
</tr>
<tr>
<td>Slope</td>
<td>$0.10/MWh</td>
</tr>
</tbody>
</table>

**Offer Curve**

- $20 @ 100 MW
- $40 @ 300 MW

**Slope**: $0.10/MWh
• Assigned 50 MW Tier 2

• Oakmont is forecasted to operate at 250 MW on average for the operating hour.

• At this output, Oakmont’s marginal cost is $35/MWh.

• The forecasted LMP at Oakmont’s bus is $45/MWh.

• Oakmont’s LOC from providing energy at a $45/MWh LMP is what sets the clearing price for reserves.

  \[ \text{LMP} = \text{LMP} = $45/MWh \]
  \[ $45/MWh - $35/MWh = $10/MWh \]

• This commitment and price are locked for the operating hour and sent to downstream applications.
From the hour-ahead solution, Oakmont has a 300 MW economic max and is assigned 50 MW of reserves.
Sequential Optimization – Reserve Assignment Implications

- Any time Oakmont is economic to provide more than 250 MW of energy
  - It incurs an opportunity cost.
  - LMP is implicitly impacted by reserves.

### Table 1: Energy Capability and Marginal Cost

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<tr>
<th>Interval</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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</thead>
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<td>$23</td>
<td>$19.00</td>
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</tbody>
</table>
Sequential Optimization – Reserve Costs

Hourly Market Clearing Price (MCP) over and undervalues reserves given the changing real-time conditions.

Inaccurate forecasts result in hour ahead commitments that may be less than optimal given real-time conditions and may result in after-the-fact make-whole payments.
Takeaways From the Example

- Under sequential optimization, Oakmont’s reserve assignment is fixed and any costs it incurs above the market clearing price are paid through out-of-market payments.

- The fact that Oakmont incurs costs in excess of the clearing price indicates that the forecasted system conditions were incorrect and that it was potentially not the most economic resource to provide reserves.
Joint Optimization Example

• Assume for this example that there is an uncommitted unit (Augusta) eligible to provide the same Tier 2 reserves at a price of $12/MWh.
• This resource was not cleared in the hour-ahead solution because its forecasted system conditions did not align with actual operating conditions.
During the operating hour, PJM operators run software that will look ahead 10 minutes to determine whether resources need to be committed for energy or reserves based on changing system conditions.

The software will determine the appropriate action to maintain the reserve requirements in the most cost-effective manner.

- RTSCED reserve assignments may differ from ASO clearing.

In the case of the Oakmont unit, during the operating hour, it is more cost efficient for it to provide energy and commit the cheaper Augusta unit for reserves.

Moving the reserve commitment from Oakmont and increasing its energy dispatch lowers the cost of both products.
Joint Optimization –
Changing Oakmont’s Reserve Commitment

Allowing Oakmont to provide energy economically allows lower cost generation to serve load, thus reducing the cost of energy.

Allowing the reserve commitment to switch to Augusta reduces the hourly reserve cost from $19/MWh to $8.75/MWh.
Joint optimization results in reserve costs that more accurately reflect system conditions. At times, this means it may result in:

- Higher reserve prices when costs that were previously settled through out of market opportunity costs are incorporated into the clearing price and paid to all resources providing reserves
- Lower reserve prices when the actual energy price is lower than projected energy price at the time the reserve assignments were made
  - Reserve market clearing price will reflect actual operating conditions rather than projected conditions with higher opportunity cost.
Joint optimization of energy and reserves provides the following benefits:

- **Reduction of out of market unit-specific opportunity cost payments**
- **Clearing prices that more accurately reflect the true cost of providing reserves since opportunity cost is better reflected in clearing prices**
- **Reduced production costs due to optimized energy and reserve assignments in response to real-time conditions (as opposed to hour ahead reserve assignments)**
- **More accurate price signals that better reflect true value of ancillary services and produce better investment signals**
- **Resources that are financially indifferent to whether they provide energy or reserves, thereby enhancing operational reliability**
RESERVES IN OTHER ISO/RTOS

Overview
Reserve Products

- Spinning Reserve (10-minute)
- Non-spinning Reserve (10-minute)
- Subregional Reserve Requirements

- Day-ahead and real-time reserve products
- Simultaneously co-optimize energy, reserves, and regulation service
- Cascading prices

Regulation-Up ≥ Spinning ≥ Non-Spinning
ERCOT Operating Reserve Products

Reserve Products (system-wide only)

- Responsive Reserve (Spinning)
- Non-spinning Reserve (30-minute)

- Day-ahead and real-time reserve products
- No co-optimization of energy and reserves
- Operating Reserve Demand Curves (ORDCs) used to price reserves in real-time
- **Cascading prices**
  - Responsive ≥ Non-Spinning
ISO New England Operating Reserve Products

Reserve Products

- 10-Minute Spinning Reserve
- 10-Minute Non-spinning Reserve
- 30-Minute Operating Reserve
- Local 30-Minute Operating Reserve

- Real-time reserve products only
- Simultaneously co-optimize energy and reserves
- Cascading prices
  10-Minute Spinning ≥ 10-Minute Non-Spinning ≥ 30-Minute Operating
Reserve Products

• Spinning Reserve (10-minute)
• Supplemental (Non-spinning) Reserve (10-minute)
• Zonal Reserve Requirements

• Day-ahead and real-time reserve products
• Simultaneously co-optimize energy, reserves, and regulation service
• Cascading prices
  Regulation ≥ Spinning ≥ Supplemental
NYISO Operating Reserve Products

Reserve Products
- 10-Minute Spinning Reserve
- 10-Minute Total Reserve
- 30-Minute Operating Reserve
- Regional Reserve Requirements
  - Day-ahead and real-time reserve products
  - Simultaneously co-optimize energy, reserves and regulation service
  - Cascading prices by reserve product and reserve region
    - Regulation $\geq$ 10-Minute Spinning $\geq$ 10-Minute Total $\geq$ 30-Minute Operating
    - LI $\geq$ SENY $\geq$ EAST $\geq$ NYCA
Additional Questions?

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