Price Formation and Scarcity Pricing

• Underlying issue EPFSTF set out to address is the appropriateness of falling prices when load rises
• Real time unit commitments to meet increasing load or declining reserves can lower price when more capacity is brought online
• Capture some of the intertemporal dynamics of the market in the reserve demand curves (ORDCs)
• Support prices at times when additional reserves provide a more economic commitment though not necessary to meet the concurrent reserve requirement
Daily Reserve Pattern

• Reserve levels vary over the course of an operating day.
  • Ample reserves when load is low
  • Closer to reserve requirement when load peaks
• When load is low, reserves exceed requirement because the most economic commitment to meet load includes long minimum run time (baseload) units.
• The market commits the additional reserves for energy needs, not to meet concurrent reserve requirement.
Daily Reserve Pattern

MW

Time of Day

Online Capacity

Load + Reserve Requirement

Load

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Fluctuations in Supply and Demand

• Suppose the total amount of reserves falls due to fluctuations in supply and demand.
• Possible outcomes:
  1. No impact because plenty of reserves
  2. Reserves fall below requirement
  3. No concurrent shortage, but market is tighter and more reserves are expected to be needed at some point
• Current ORDC addresses 1 and 2.
• Outcome 3. creates a demand for reserves that may lead to a real time unit commitment.
Demand for Additional Reserves

- Operator anticipates persistent falling reserves
- Need to bring more capacity online to maintain energy and reserves through the next peak period
- Can purchase more reserves now or later
- An economic approach to the decisions depends on
  - The relative effectiveness of reserves brought online now or closer to the peak period
  - The relative cost of reserves brought online now or closer to the peak period
- Demand is the expected cost savings of purchasing more now to avoid a higher cost later.
Effectiveness of Reserves Now and Later

- Reserves purchased hours ahead of time may no longer be online later.
- Reserves purchased too close to when needed may not come online quickly enough.
- One MW of reserve purchased later, during the daily peak, provides one full MW of peak reserves.
- One MW of reserve purchased now may provide less than one MW of peak reserves.
- Reserve effectiveness is the probability that a MW of reserves now will meet the peak reserve requirement.
All combinations of reserves now and later along the curve satisfy the same level of need.
Cost of Reserves Now and Later

• The need for more reserves occurs later, during the peak period, when prices are higher.
• Prices are currently lower.
• As the relative price of reserves now versus later falls, purchase more now.
Choice of Reserves Now and Later

The economic choice, $N_1$ MW of reserves now and $L_1$ MW of reserves later, depends on the relative price of reserves now vs. reserves later.

Slope = $-\frac{\text{Price}_N}{\text{Price}_L}$
A lower price for reserves now or a higher price for reserves later leads to a shift toward purchasing more now.

\[ \text{Slope} = - \frac{\text{Price}_N}{\text{Price}_L} \]
Deriving Demand for Reserves Now and Later

• The relationship between the increasing economic purchase of reserves now and the falling price of reserves now is the demand curve for additional reserves now.

• The demand curve equates the relative effectiveness per dollar of reserves now to the relative effectiveness per dollar of reserves later.

\[
\frac{\text{Effectiveness Now}}{\text{Price Now}} = \frac{\text{Effectiveness Later}}{\text{Price Later}}
\]
As the price of reserves now falls from P1 to P3, the economic choice is to buy more reserves now. With a constant price for reserves later, the lower price means higher achievable levels of expected need at the same cost.
The demand curve contains the prices and economic choice of reserves now for each price.
Historical PJM Reserves

- IMM analyzed historic five minute reserves for 2015, 2016, and 2017.
- Average hourly reserves varied from small shortages to more than 1,600 MW above the requirement.
- Daily reserve patterns vary by season.
Winter Daily Pattern

- Average of RTO Synch Reserve
- Average of MAD Synch Reserve
- Average of RTO Primary Reserve
- Average of MAD Primary Reserve

Hour of Day

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Tight Days

• Tight days are days when reserves fall close to the reserve requirement during peak load periods.

• Tight day definition: primary reserves within 150 MW of the reserve requirement for 36 five minute intervals during the peak hours of the day.

• Tight days include:
  • Annual peak load days in 2015, 2016, and 2017
  • Winter peak load days in 2015 and 2017
  • Highest balancing uplift days 2016 and 2017
<table>
<thead>
<tr>
<th>Season</th>
<th>Load Level</th>
<th>Tight Days</th>
<th>Percent of Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Over 125 GW</td>
<td>11</td>
<td>68.8%</td>
</tr>
<tr>
<td>Summer</td>
<td>Over 125 GW</td>
<td>56</td>
<td>50.9%</td>
</tr>
<tr>
<td>Summer</td>
<td>100 to 125 GW</td>
<td>64</td>
<td>45.7%</td>
</tr>
<tr>
<td>Winter</td>
<td>100 to 125 GW</td>
<td>78</td>
<td>45.3%</td>
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<tr>
<td>Winter</td>
<td>85 to 100 GW</td>
<td>33</td>
<td>43.4%</td>
</tr>
<tr>
<td>Fall</td>
<td>0 to 85 GW</td>
<td>15</td>
<td>38.5%</td>
</tr>
<tr>
<td>Fall</td>
<td>100 to 125 GW</td>
<td>22</td>
<td>37.3%</td>
</tr>
<tr>
<td>Fall</td>
<td>85 to 100 GW</td>
<td>57</td>
<td>35.8%</td>
</tr>
<tr>
<td>Spring</td>
<td>0 to 85 GW</td>
<td>19</td>
<td>32.8%</td>
</tr>
<tr>
<td>Spring</td>
<td>100 to 125 GW</td>
<td>17</td>
<td>30.9%</td>
</tr>
<tr>
<td>Winter</td>
<td>Over 125 GW</td>
<td>6</td>
<td>30.0%</td>
</tr>
<tr>
<td>Summer</td>
<td>85 to 100 GW</td>
<td>6</td>
<td>23.1%</td>
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<tr>
<td>Spring</td>
<td>85 to 100 GW</td>
<td>35</td>
<td>21.6%</td>
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<tr>
<td>Spring</td>
<td>Over 125 GW</td>
<td>-</td>
<td>0.0%</td>
</tr>
<tr>
<td>Winter</td>
<td>0 to 85 GW</td>
<td>-</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Calculating the Benefit of Additional Reserves

- Some probability of a tight day regardless of the level of reserves.
- As reserves shrink, the probability of a tight day should increase.
- The purchase of more reserves can decrease the probability of a tight day.
- Relative effectiveness of a reserve purchase now instead of later is
  - Probability of a tight day given the reserve level now
  - Minus the overall probability of a tight day
The Cost of Additional Reserves

• The cost of additional reserves during the peak period is no greater than the peak period LMP, which is the next best option for available capacity.
• Multiplying the cost by the relative effectiveness of reserves now vs. later provides the willingness to pay for more reserves now.
### Deriving the Cost of Reserves at Peak from the Percent of Tight Days Given the Reserve Level at 6:00 AM for Summer High Load Days

<table>
<thead>
<tr>
<th>Additional Reserve MW</th>
<th>Percent of Tight Days Given Reserve Level at 6:00 AM</th>
<th>Difference in Percent Tight Days Given Reserve Level and Overall</th>
<th>Peak Hour Average LMP</th>
<th>Willingness to Pay for Additional Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>840</td>
<td>71.4%</td>
<td>36.0%</td>
<td>$71.00</td>
<td>$25.57</td>
</tr>
<tr>
<td>855</td>
<td>62.5%</td>
<td>27.1%</td>
<td>$71.00</td>
<td>$19.23</td>
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<tr>
<td>890</td>
<td>50.0%</td>
<td>14.6%</td>
<td>$71.00</td>
<td>$10.35</td>
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<tr>
<td>1,275</td>
<td>46.9%</td>
<td>11.5%</td>
<td>$71.00</td>
<td>$8.14</td>
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<tr>
<td>1,565</td>
<td>44.4%</td>
<td>9.0%</td>
<td>$71.00</td>
<td>$6.41</td>
</tr>
<tr>
<td>1,685</td>
<td>39.5%</td>
<td>4.1%</td>
<td>$71.00</td>
<td>$2.92</td>
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<td>1,785</td>
<td>37.8%</td>
<td>2.4%</td>
<td>$71.00</td>
<td>$1.68</td>
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<tr>
<td>1,890</td>
<td>37.0%</td>
<td>1.5%</td>
<td>$71.00</td>
<td>$1.09</td>
</tr>
<tr>
<td>2,052</td>
<td>36.2%</td>
<td>0.8%</td>
<td>$71.00</td>
<td>$0.54</td>
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<td>2,238</td>
<td>35.4%</td>
<td>0.0%</td>
<td>$71.00</td>
<td>$0.00</td>
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</tbody>
</table>
Intertemporal ORDC Example
Summer High Load 6:00 AM