Lost Opportunity Cost: Ancillary Services

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Resources can participate in the PJM Energy Market through the Day Ahead, Real-Time and/or Ancillary Services market.

PJM jointly optimizes energy and reserves (synchronized and non-synchronized).

Energy and reserve MWs are substitute products:
- MWs used to serve energy cannot simultaneously be used to provide reserves.
Incentive Compatibility

• Generation resources forgo energy market revenues when providing MWs for reserves

• Energy and reserve payments must be incentive compatible with dispatch instructions
  – All payments must make the marginal reserve supplier indifferent between providing reserves and energy
Lost opportunity cost is the forgone energy revenues incurred by a generation resource that provides a PJM required ancillary service.
Example: Synchronized Reserves

• Energy and Reserve MW and Prices are jointly determined
  – Objective: minimize total production costs subject to system conditions, resource operating parameters and reserve requirement constraint

• Energy assignments are merit ordered
  – Resources with the lowest $/MWh offers are assigned first
  – The marginal energy supplier sets the energy price

• Reserve assignments are merit ordered
  – Resources with the lowest lost opportunity costs are assigned first
  – The marginal reserve supplier sets the reserve price
Example: Merit Ordered Lost Opportunity Cost

- Lost Opportunity Cost = LMP – Marginal Cost

- Holding LMP constant, lost opportunity cost decreases as marginal cost increases

- The most expensive resources for energy will have the lowest lost opportunity cost
  - Merit ordered reserve assignment dictates that these resources will be assigned first in the reserve market
<table>
<thead>
<tr>
<th>Generator</th>
<th>Energy Offer ($/MWh)</th>
<th>Generator Capacity (MW)</th>
<th>Reserve Capability (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$25</td>
<td>300</td>
<td>80</td>
</tr>
<tr>
<td>B</td>
<td>$40</td>
<td>400</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>$70</td>
<td>200</td>
<td>120</td>
</tr>
</tbody>
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For simplicity, assume that reserve bids are zero
Example: Energy Assignments – No Reserve Constraint

Load = 630 MW

Generator A
- 300 MW
- $25 MWh

Generator B
- 330 MW
- $40 MWh

Generator C
- Unloaded Capacity
- $70 MWh

Energy Assignment
- Green
Unloaded Capacity
- Gray
Energy Offer
- Dotted Green
Energy & Reserve Assignments w/Reserve Constraint

Load = 630 MW
Reserve Requirement = 200 MW

Generator A
- 300 MW
- $25 MWh
- $45 MWh

Generator B
- 320 MW
- $30 MWh
- $40 MWh
- $30 MWh

Generator C
- 120 MW
- 10 MW
- $0 MWh
- $70 MWh

Lost Opportunity Cost
Energy Offer
Unloaded Capacity
Reserve Capability
Energy Assignment
Reserve Assignment
Example: Energy & Reserve Prices w/Reserve Constraint

Load = 630 MW
Reserve Requirement = 200 MW

Generator A
- 300 MW

Generator B
- 320 MW
- 80 MW
- $30 MWh

Generator C
- 120 MW
- 10 MW
- $70 MWh

Legend:
- Energy Assignment
- Reserve Assignment
- Unloaded Capacity
- Reserve Capability
- LMP
- Reserve Price
Example: Lost Opportunity Cost is Incentive Compatible

<table>
<thead>
<tr>
<th>Generator B Offer and Assignments</th>
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<tbody>
<tr>
<td><strong>Energy Price (LMP)</strong></td>
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<tr>
<td><strong>Reserve Price (LOC)</strong></td>
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<tr>
<td><strong>Energy Offer</strong></td>
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<tr>
<td><strong>Reserve Offer</strong></td>
</tr>
<tr>
<td><strong>Generator Capacity</strong></td>
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<tr>
<td><strong>Assigned Energy</strong></td>
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<tr>
<td><strong>Assigned Reserve</strong></td>
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<th>Energy Market Net Revenues at Economic Dispatch Point</th>
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<td><strong>LMP</strong></td>
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<table>
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<th>Energy Market Net Revenues at Final Dispatch Point</th>
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<tr>
<td><strong>LMP</strong></td>
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<td>--------</td>
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<td>$70</td>
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Forgone energy net revenues to provide reserves: $2,400

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<th>Reserve Market Net Revenues</th>
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<tr>
<td><strong>LOC</strong></td>
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<tr>
<td>$30</td>
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Reserve market net revenues are exactly equal to the forgone energy market net revenues - thus the marginal reserve supplier is neutral between supplying reserves or energy.
Unit vs. Demand Resource Offers

• Unit
  – Energy and reserve optimized by market clearing engine
  – LOC for revenue foregone in the energy market

• Demand Resource
  – Energy and reserve MW allocation specified by participant
  – No LOC because no product substitution

Energy Reserves
MW amount is optimized by engine

Energy Reserves
MW amount is specified by participant