Real-Time LMP and Impacts on Uplift

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Locational Marginal Price

\[ \text{LMP} = \text{System Energy Price} + \text{Transmission Congestion Cost} + \text{Cost of Marginal Losses} \]

- What is included in the LMP?
  - System Energy Price
  - Transmission Congestion Cost(s)
  - Cost of Marginal Losses
  - Effect of Reserve Shortages
• What is not included in the LMP?
  – For resources not on the margin, any difference between the LMP and the resource's marginal cost where LMP < marginal cost
  – For manually dispatched units, any lost opportunity between LMP and the marginal cost of the resource’s dispatch point where LMP > marginal cost
  – Generator start up and no load costs
  – DR Shutdown cost
Marginal Resources

- There will always be at least one marginal resource
  - System Energy Resource
- Additional marginal resources for each binding transmission constraint
- In most cases, there are multiple marginal resources for a given time interval
Resources Eligible to Set Price

- Online generators dispatchable by PJM
- Dispatchable Transactions following PJM’s dispatch instructions
- Economic Demand Response
- Price Responsive Demand
- Emergency Demand Response
- Emergency Import Transactions
- Generation from emergency segments of units already on-line and operating in the real-time energy market
Resources Not Eligible to Set Price

- Manually dispatched generators
- Units that have the Fixed Gen flag selected in the Market Unit Hourly tab in Markets Gateway
- Must Run units
- Units that are in start up or shut down mode
- Units that are condensing
When is a Resource Marginal?

• A resource is marginal when it supplies the next MW of generation or demand reduction to meet load or control a transmission constraint
  – System conditions heavily influence where that next MW is needed from the supply stack
    • Weather
    • Interchange
    • Accuracy of the load forecast
Why Wasn’t My Resource Marginal?

- Artificial dispatchable range for Inflexible resources
  - CTs
  - Emergency Demand Response
- Generator runs to control a transmission constraint that never binds
- Imports have the ability to suppress the price when they are not needed
Examples

• Minimum Run Time
• Unit Setting LMP
  – Startup/No-Load Cost
• Multi-Unit Dispatch Example
• Name = Pebble Beach 1
• Start/Notification (Lead) Time = 6 hours
• Min Run Time = 4 hours
• Min = 300 MW
• Max = 400 MW
• Offer Price =
  – 300 MW @ $50/MWh
  – 400 MW @ $60/MWh
• Startup Cost = $10,000
• No-Load = $2,000/hr
Formulas

- LMP Credits = MW * LMP
- Offer Curve = price interpolated from offer Curve at MW point
- Offer Cost = area under offer curve at MW point
- Amortized Startup = Startup cost / run-time
  - $10,000 / 4hrs = $2,500/hr
- Total Cost = Offer Cost + Amortized Startup + No-Load
- Hourly Net = LMP Credits – Total Cost
  - Negative if running at a loss for the hour
<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
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<tbody>
<tr>
<td>MW</td>
<td>0</td>
<td>400</td>
<td>400</td>
<td>300</td>
<td>300</td>
<td>0</td>
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<tr>
<td>LMP ($/MWh)</td>
<td>30</td>
<td>65</td>
<td>75</td>
<td>20</td>
<td>25</td>
<td>35</td>
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<tr>
<td>LMP Credits ($/MWh)</td>
<td>0</td>
<td>26,000</td>
<td>30,000</td>
<td>6,000</td>
<td>7,500</td>
<td>0</td>
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<td>Offer Curve ($/MWh)</td>
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<td>60</td>
<td>60</td>
<td>50</td>
<td>50</td>
<td>0</td>
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<tr>
<td>Offer Cost ($)</td>
<td>0</td>
<td>20,500</td>
<td>20,500</td>
<td>15,000</td>
<td>15,000</td>
<td>0</td>
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<tr>
<td>Amortized Startup ($)</td>
<td>0</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>0</td>
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<tr>
<td>No Load ($/hr)</td>
<td>0</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>0</td>
</tr>
<tr>
<td>Total Cost ($)</td>
<td>0</td>
<td>25,000</td>
<td>25,000</td>
<td>19,500</td>
<td>19,500</td>
<td>0</td>
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<tr>
<td>Hourly Net ($)</td>
<td>0</td>
<td>$1,000</td>
<td>$5,000</td>
<td>($13,500)</td>
<td>($12,000)</td>
<td>0</td>
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</table>
• Unit running in real-time at PJM direction
• No other credits accrued during operating day
• Unit following dispatch
• Unit operating at a loss for the day
  – Sum of “Hourly Net” row is \(\text{($19,500)}\)
  – Unit would be paid BOR in this case
• Allocation would depend on BORCA chart
<table>
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<td>MW</td>
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<td>320</td>
<td>330</td>
<td>390</td>
<td>310</td>
<td>0</td>
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<tr>
<td>LMP ($/MWh)</td>
<td>30</td>
<td>52</td>
<td>53</td>
<td>59</td>
<td>51</td>
<td>35</td>
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<tr>
<td>LMP Credits ($/MWh)</td>
<td>0</td>
<td>16,640</td>
<td>17,490</td>
<td>23,010</td>
<td>15,810</td>
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<td>Offer Curve ($/MWh)</td>
<td>0</td>
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<td>59</td>
<td>51</td>
<td>0</td>
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<td>16,020</td>
<td>16,545</td>
<td>19,905</td>
<td>15,505</td>
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<tr>
<td>Amortized Startup ($)</td>
<td>0</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>2,500</td>
<td>0</td>
</tr>
<tr>
<td>No Load ($/hr)</td>
<td>0</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
<td>0</td>
</tr>
<tr>
<td>Total Cost ($)</td>
<td>0</td>
<td>20,520</td>
<td>21,045</td>
<td>24,405</td>
<td>20,005</td>
<td>0</td>
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<tr>
<td>Hourly Net ($)</td>
<td>0</td>
<td>($3,880)</td>
<td>($3,555)</td>
<td>($1,395)</td>
<td>($4,195)</td>
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• Unit running in real-time at PJM direction
• No other credits accrued during operating day
• Unit following dispatch
• Unit is marginal for its entire run period
  – LMP only covers marginal costs of the unit
  – Startup and no load require a make whole
  – Sum of “Hourly Net” row is ($13,025)
  – Unit would be paid BOR in this case
• Allocation would depend on BORCA chart
**Economic Dispatch and LMP**

**LOAD = 175 MW**

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<tr>
<th>Plant</th>
<th>MW</th>
<th>$</th>
<th>Capacity</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td>A</td>
<td>300</td>
<td>$60</td>
<td>300 MWs</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>B</td>
<td>200</td>
<td>$80</td>
<td>200 MWs</td>
<td>100</td>
<td>200</td>
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<tr>
<td>C</td>
<td>400</td>
<td>$100</td>
<td>400 MWs</td>
<td>200</td>
<td>400</td>
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Load: 175 MWs

PJM

LMP: $???
**Economic Dispatch and LMP**

**LOAD = 175 MW**

- **A**
  - MW: $60
  - Capacity: 300 MWs
  - Min = 100 MW
  - Max = 300 MW

- **B**
  - MW: $60
  - Capacity: 200 MWs
  - Min = 100 MW
  - Max = 200 MW

- **C**
  - MW: $80
  - Capacity: 400 MWs
  - Min = 200 MW
  - Max = 400 MW

**Load**
- 175 MWs

**PJM**
- $60
- LMP

**Marginal**
Economic Dispatch and LMP

LOAD = 275 MW

A
MW $60
Capacity 300 MWs
Min = 100 MW
Max = 300 MW

B
MW $80
Capacity 200 MWs
Min = 100 MW
Max = 200 MW

C
MW $100
Capacity 400 MWs
Min = 200 MW
Max = 400 MW

PJM

Load
275 MWs

PJM

$???
LMP
Economic Dispatch and LMP

LOAD = 275 MW

Marginal

A
MW
$60
Capacity
300 MWs
Min = 100 MW
Max = 300 MW

B
MW
$80
Capacity
200 MWs
Min = 200 MW
Max = 400 MW

C
MW
$100
Capacity
400 MWs
Min = 200 MW
Max = 400 MW

Load
275 MWs

PJM

$60
LMP

www.pjm.com
**Economic Dispatch and LMP**

**LOAD = 350 MW**

A

MW $60
Capacity 300 MWs

Min = 100 MW
Max = 300 MW

MW = ?

B

MW $80
Capacity 200 MWs

Min = 100 MW
Max = 200 MW

MW = ?

C

MW $100
Capacity 400 MWs

Min = 200 MW
Max = 400 MW

Load 350 MWs

PJM

LMP

$???
LOAD = 350 MW

Load
350 MWs

PJM
$ 60
LMP

A
MW $60
Capacity 300 MWs
Min = 100 MW
Max = 300 MW
MW = 250 MW

B
MW $80
Capacity 200 MWs
Min = 100 MW
Max = 200 MW
MW = 100 MW

C
MW $100
Capacity 400 MWs
Min = 200 MW
Max = 400 MW

Marginal
• Generators A and B must be running to meet a load level of 350 MW
• Generator A must be reduced to accommodate the 100 MW min of Generator B
• Because Generator A has 50 MW of room left, and is the cheapest option to service the next MW, Generator A is marginal
Economic Dispatch and LMP

LOAD = 550 MW

A

MW $60
Capacity 300 MWs
Min = 100 MW
Max = 300 MW
MW = ?

B

MW $80
Capacity 200 MWs
Min = 100 MW
Max = 200 MW
MW = ?

C

MW $100
Capacity 400 MWs
Min = 200 MW
Max = 400 MW
MW = ?

Load 550 MWs

PJM

$???
LMP
LOAD = 550 MW

**Marginal**

A
MW $60
Capacity 300 MWs
Min = 100 MW
Max = 300 MW
MW = 250

B
MW $80
Capacity 200 MWs
Min = 100 MW
Max = 200 MW
MW = 100

C
MW $100
Capacity 400 MWs
Min = 200 MW
Max = 400 MW
MW = 200

Load
350 MWs

PJM

$ 60
LMP
• All generators must be running to meet a load level of 550 MW
• Generators A and B must be reduced to accommodate the 200 MW min of Generator C
• Because Generator A has 50 MW of room left, and is the cheapest option to service the next MW, **Generator A is marginal**

www.pjm.com
LOAD $\leq 300$ MW

Generator A is the only unit online and it is marginal
$300 \text{ MW} < \text{Load} \leq 400 \text{ MW}

B is on at min. A is still marginal because it was reduced to accommodate B’s min and provide the next cheapest MW.
400 MW < Load <= 500 MW

A and B are both on. A is fully loaded at 300 MW. B is now marginal for energy and therefore sets LMP.
A, B and C are all on. Both A and B are reduced by 100 MW to accommodate the min of unit C. Unit A is marginal as it provides the next cheapest MW.
600 MW < Load <= 700 MW

Same as previous but now Unit A has been fully dispatched. Unit B now marginal. Unit C still sitting at min.
Load > 700 MW

Units A and B at max. Unit C is marginal and setting LMP.
Marginal Resource

- Not always the most expensive unit online
- This would send the wrong signal to the generator being dispatched for the next MW
- Can bounce around depending on unit parameters
- Follows the non-zero sloped curve in the next slides (unit being dispatched up)
“Price Formation” Docket

Order 831
Offer cap level and offer validation

Order 825
Sub-hourly settlement and transient shortage pricing

Uplift Allocation NOPR

Fast Start Pricing NOPR