Locational Marginal Pricing Components
Agenda

- LMP Components
- 5 Bus Model
- Shadow Prices
- Statistics
- LMP Simulation Demo
What is LMP?

• Pricing method PJM uses to:
  – price energy purchases and sales in PJM Market
  – price transmission congestion costs to move energy within PJM RTO
  – price losses on the bulk power system
How does PJM Use LMP?

• Generators get paid at generation bus LMP
• Loads pay at load bus LMP
• Transactions pay differential in source and sink LMP
Locational Marginal Price

System Marginal Price (SMP)
- Incremental price of energy for the system, given the current dispatch, at the load weighted reference bus
  - SMP is LMP without losses or congestion
- Same price for every bus in PJM (no locational aspect)
- Calculated both in day ahead and real time
**Locational Marginal Price**

LMP = System Marginal Price + Congestion Component + Marginal Loss Component

- **Congestion Component (CLMP)**
  - Represents price of congestion for binding constraints
    - Calculated using the Shadow Price
  - Will be zero if no constraints (Unconstrained System)
    - Will vary by location if system is constrained
  - Used to price congestion
    - Load pays Congestion Price
    - Generation is paid Congestion Price
  - Calculated both in day ahead and real time
Operational Limits

• **Thermal Limits** - Thermal limits are due to the thermal capability of power system equipment

• **Voltage Limits** - Utility and customer equipment is designed to operate at a certain supply voltage

• **Stability Limits** - Refers to the power system maintaining a state of equilibrium
Control Actions

- There are three basic types of actions that can be performed to control the flow of power on the electric system:

1. System Reconfiguration
2. Transaction Curtailments
3. Redispach Generation
When Constraints Occur...

• Delivery limitations prevent use of “next least-cost generator”
• Higher-cost generator closer to load must be used to meet demand
• Cost expressed as “security constrained redispatch cost”
Security Constrained Re-Dispatch

Control Area
Constrained System

Low Cost Generator
$$

High Cost Generator
$$$$

Higher cost Generator more advantageously located relative to transmission system limit

Transmission "Bottleneck" or Constraint
Congestion effects on LMP and Revenues

• When the bus is **upstream** of a constraint
  – Congestion Component is **negative**
  – Results in **negative** revenues to unit

• When the bus is **downstream** of a constraint
  – Congestion Component is **positive**
  – Results in **positive** revenues to unit
Constraints & Marginal Units

- There will always be at least one marginal unit
  - System Energy Unit

- There will be an additional marginal unit for each binding constraint

- It is possible and, in fact likely, that there will be multiple marginal units for a given time interval
Marginal Loss Component (MLMP)

- Represents price of marginal losses
  - Transmission losses are priced according to marginal loss factors which are calculated at a bus and represent the percentage increase in system losses caused by a small increase in power injection or withdrawal
    - Calculated using penalty factors
- Will vary by location
- Used to price losses
  - Load pays the Loss Price
  - Generation is paid the Loss Price
- Calculated both in day-ahead and real-time
Marginal Loss effects on LMP and Revenues

• When the bus is electrically distant from the load
  – Marginal Loss Component is negative
  – Results in negative revenues to unit

• When the bus is electrically close to the load
  – Marginal Loss Component is positive
  – Results in positive revenues to unit
What would you expect to see?

Congestion Component of LMP?

Loss Component of LMP?

200 miles

Constraint

30 miles

Congestion Component of LMP? (+)

Loss Component of LMP? (+)

(-)

(+)
Agenda

• LMP Components
• 5 Bus Model
• Shadow Prices
• Statistics
• LMP Simulation Demo
LMP Examples

5-Bus Model Examples

- Alta: 110 MW, $14/MWh
- Park City: 100 MW, $15/MWh
- Sundance: 200 MW, $40/MWh
- Solitude: 520 MW, $30/MWh
- 600 MW, $10/MWh (Brighton)

230 MW Thermal Limit
Example # 1 - 5 Bus Transmission Grid

Generator Offers

- 600 MW $10/MWh Brighton
- 200 MW $40/MWh Sundance
- 110 MW $14/MWh Alta
- 100 MW $15/MWh Park City
- 520 MW $30/MWh Solitude

System Loads = 669 MW
System Losses = 17 MW

230 MW Thermal Limit

Sundance

223 MW
Example #1 - 5 Bus Transmission Grid

System Loads = 669 MW
System Losses = 17 MW

Dispatch & Energy Flow

Brighton
600 MW
$10/MWh
PF = 1.0625

Alta
86 MW
110 MW
$14/MWh
PF = 1.0492

Park City
100 MW
$15/MWh
PF = 1.0492

B Sundance
200 MW
$40/MWh
PF = 1.0247

C
223 MW

E
230 MW
Thermal Limit

D
520 MW
$30/MWh
PF = 1.0000

Sundance
223 MW

Solitude
223 MW

System Loads = 669 MW
System Losses = 17 MW

PF = 1.0492

PF = 1.0492

PF = 1.0625

PF = 1.0000

PF = 1.0247
System Energy Price = LMP at the Reference Bus (where Congestion & Losses = 0)

Reference or “Slack” Bus is the “electrical load center” of the system

Losses are calculated using the System Energy Price & the Penalty Factor (Pf)
## Example # 1 - Summary

<table>
<thead>
<tr>
<th>Unit</th>
<th>Offer Price</th>
<th>Penalty Factor</th>
<th>Adjusted Offer</th>
<th>System Energy Price</th>
<th>Loss Price</th>
<th>Congestion Price</th>
<th>Total LMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brighton</td>
<td>$10.00</td>
<td>1.0625</td>
<td>$10.625</td>
<td>$14.69</td>
<td>-$0.86</td>
<td>$0.00</td>
<td>$13.83</td>
</tr>
<tr>
<td>Alta</td>
<td>$14.00</td>
<td>1.0492</td>
<td>$14.688</td>
<td>$14.69</td>
<td>-$0.69</td>
<td>$0.00</td>
<td>$14.00</td>
</tr>
<tr>
<td>Park City</td>
<td>$15.00</td>
<td>1.0492</td>
<td>$15.738</td>
<td>$14.69</td>
<td>-$0.69</td>
<td>$0.00</td>
<td>$14.00</td>
</tr>
<tr>
<td>Solitude</td>
<td>$30.00</td>
<td>1.0000</td>
<td>$30.000</td>
<td>$14.69</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$14.69</td>
</tr>
<tr>
<td>Sundance</td>
<td>$40.00</td>
<td>1.0247</td>
<td>$40.988</td>
<td>$14.69</td>
<td>-$0.35</td>
<td>$0.00</td>
<td>$14.33</td>
</tr>
</tbody>
</table>

- **Marginal Unit**
- **Reference Bus**

*Unit Running*
*Unit Not Running*

Loss and Congestion Components of LMP are “0” at the Reference Bus.
Example # 1 - 5 Bus Transmission Grid

LMPs

- **Brighton**
  - 600 MW
  - $10/MWh
  - PF = 1.0625

- **Alta**
  - 600 MW
  - $10/MWh
  - PF = 1.0625

- **Park City**
  - 223 MW
  - 223 MW
  - 110 MW
  - $14/MWh
  - PF = 1.0492

- **Solitude**
  - 200 MW
  - $40/MWh
  - PF = 1.0247

- **Sundance**
  - 223 MW
  - 223 MW
  - 223 MW
  - $15/MWh
  - PF = 1.0492

Area Load = 669
Area Losses = 17 MW
Area Generation = 686

LMPs:

- **LMP = $13.83**
  - **Brighton**
  - **Alta**

- **LMP = $14.00**
  - **Park City**

- **LMP = $14.33**
  - **Sundance**
  - **Solitude**

Marginal Unit
Reference Bus

PF = 1.0492
PF = 1.000
PF = 1.0247
Agenda

• LMP Components
• 5 Bus Model
• Shadow Prices
• Statistics
• LMP Simulation Demo
Binding Constraints and Shadow Prices

• Binding constraints limit the ability to improve the objective function
  – If a binding constraint is relaxed, or made less restrictive, a better solution is possible

• The shadow price is the marginal improvement caused by relaxing the constraint
  – In energy markets, a shadow price shows the savings in Bid Production Cost if binding constraint is relaxed by 1MW

• Shadow prices tell us how much more money we can make (or save) by improving one of our limiting factors or boundary conditions
Shadow Price

Area 1

$60

ON G1
ON G2
ON G4
OFF G5

Load = 200MW

Area 2

$90

G3 ON

Load = 600MW

Limit = 400MW

Total Production Cost = (600*60) + (200*90) = $54,000
**Shadow Price**

<table>
<thead>
<tr>
<th>Area 1</th>
<th>Area 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load = 200MW</td>
<td>Load = 600MW</td>
</tr>
</tbody>
</table>

Limit = 401MW

- **ON** G1
- **ON** G2
- **ON** G4
- **OFF** G5

$60

$90

Total Production Cost = (601*60) + (199*90) = $53,970
Shadow Prices

- (Before: 400 MW limit) Total production cost is $54,000
- (After: 401 MW limit) Total production cost is $53,970
- “Relaxing” constraint limit by 1 MW saved us $30 in total production costs
- Difference between the “Before” and “After” case is the Shadow price = $30
LMP Components

System Energy Price

System Energy Price

Marginal loss Sensitivity factor

Constraint_A Shadow Price

DFAX_A

System Energy Price = Marginal Loss Component = Congestion Component_A

LMP
### System Energy Price

| System Energy Component |  $33.11$ | $X$ | $\times$ 1.0 | $=$ | $33.11$ |

### Loss Component

| Loss Component | $33.11$ | $X$ | Marginal Loss Sensitivity Factor | $=$ | $(1.04)$ |

### Congestion Components

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Constraint Shadow Price</th>
<th>$X$</th>
<th>DFAX</th>
<th>$=$</th>
<th>Congestion Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraint A</td>
<td>$-9.96$</td>
<td>$X$</td>
<td>$-0.3151$</td>
<td>$=$</td>
<td>$3.14$</td>
</tr>
<tr>
<td>Constraint B</td>
<td>$-13.88$</td>
<td>$X$</td>
<td>$0.1225$</td>
<td>$=$</td>
<td>$(1.70)$</td>
</tr>
<tr>
<td>Constraint C</td>
<td>$-26.06$</td>
<td>$X$</td>
<td>$-0.2151$</td>
<td>$=$</td>
<td>$5.61$</td>
</tr>
<tr>
<td>Constraint D</td>
<td>$-5.48$</td>
<td>$X$</td>
<td>$-0.0200$</td>
<td>$=$</td>
<td>$0.11$</td>
</tr>
</tbody>
</table>

**LMP = $39.23$**

- Which constraints does raising unit output help?
- Which constraints does raising unit output hurt?
- Is close to center of system load?
- **Bonus Question – How many marginal units does this system have?**
<table>
<thead>
<tr>
<th>Constraints A, C and D</th>
<th>( \text{System Energy Price} \times X \times *1.0 = \text{System Energy Component} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>System Energy Component</td>
</tr>
<tr>
<td></td>
<td>$33.11 X 1.0 = $33.11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Loss Component</th>
<th>( \text{System Energy Price} \times X \times \text{Marginal Loss Sensitivity Factor} = \text{Marginal Loss Component} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loss Component $33.11 X -0.0315 = ($1.04)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Congestion Components</th>
<th>( \text{Constraint Shadow Price} \times X \times \text{DFAX} = \text{Congestion Component} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraint A</td>
<td>Constraint A $-9.96 X -0.3151 = $3.14</td>
</tr>
<tr>
<td>Constraint B</td>
<td>Constraint B $-13.88 X 0.1225 = ($1.70)</td>
</tr>
<tr>
<td>Constraint C</td>
<td>Constraint C $-26.06 X -0.2151 = $5.61</td>
</tr>
<tr>
<td>Constraint D</td>
<td>Constraint D $-5.48 X -0.0200 = $0.11</td>
</tr>
</tbody>
</table>

\[
\text{LMP} = $39.23
\]

- Which constraints does raising unit output help? Constraints A, C and D
- Which constraints does raising unit output hurt? Constraint B
- Is close to center of system load? No
- **Bonus Question – How many marginal units does this system have?** 5
Example # 2 - 5 Bus Transmission Grid

Constrained System Loads + Losses = 921

Brighton
- 600 MW
  - $10/MWh

Alta
- 110 MW
  - $14/MWh

Park City
- 100 MW
  - $15/MWh

Load = 300 MW

230 MW Thermal Limit

Sundance
- 200 MW
  - $40/MWh

Solitude
- 520 MW
  - $30/MWh

Loads = 300 MW

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Example # 2 - 5 Bus Transmission Grid

Dispatch Solution Ignoring Thermal Limit

System Loads = 900 MW
System Losses = 21 MW

Dispatched at 600 MW
Brighton

600 MW $10/MWh

Dispatched at 110 MW
Alta

110 MW $14/MWh

Dispatched at 110 MW

230 MW Thermal Limit

200 MW $40/MWh
Sundance

300 MW

520 MW $30/MWh

600 MW Dispatched at 600 MW

100 MW $15/MWh

110 MW

System Loads = 900 MW
System Losses = 21 MW

193

144

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Example # 2 - 5 Bus Transmission Grid

Actual Dispatched Generation

- **Brighton**: 509 MW
  - Dispatched at 509 MW
  - 600 MW
  - $10/MWh

- **Alta**: 110 MW
  - Dispatched at 110 MW
  - 100 MW
  - $14/MWh

- **Park City**:
  - 100 MW
  - Dispatched at 100 MW
  - $15/MWh

- **Sundance**:
  - 300 MW
  - 300 MW
  - 300 MW
  - 520 MW
  - Dispatched at 196 MW
  - $30/MWh

- **Solitude**:
  - 200 MW
  - $40/MWh

System Loads = 900 MW
System Losses = 15 MW

Dispatched at 509 MW
Dispatched at 196 MW
Dispatched at 100 MW
Dispatched at 110 MW

Actual Dispatched Generation

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### Calculate Shadow Price and Congestion Price

**Production Cost calculated using a DC Power Flow Solution**

#### Production Cost with 230 MW across Brighton - Sundance line

<table>
<thead>
<tr>
<th>Unit</th>
<th>MW</th>
<th>Price</th>
<th>No Load</th>
<th>Production Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brighton</td>
<td>485</td>
<td>10</td>
<td>$399.80</td>
<td>$5,249.80</td>
</tr>
<tr>
<td>Alta</td>
<td>110</td>
<td>14</td>
<td>$100.00</td>
<td>$1,640.00</td>
</tr>
<tr>
<td>Park City</td>
<td>100</td>
<td>15</td>
<td>$100.00</td>
<td>$1,600.00</td>
</tr>
<tr>
<td>Solitude</td>
<td>205</td>
<td>30</td>
<td>$100.00</td>
<td>$6,250.00</td>
</tr>
<tr>
<td>Sundance</td>
<td>0</td>
<td>40</td>
<td>$100.00</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>900</td>
<td></td>
<td></td>
<td>$14,739.80</td>
</tr>
</tbody>
</table>

**Production Cost with 231 MW across Brighton - Sundance line**

<table>
<thead>
<tr>
<th>Unit</th>
<th>MW</th>
<th>Price</th>
<th>No Load</th>
<th>Production Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brighton</td>
<td>488</td>
<td>10</td>
<td>$399.80</td>
<td>$5,279.80</td>
</tr>
<tr>
<td>Alta</td>
<td>110</td>
<td>14</td>
<td>$100.00</td>
<td>$1,640.00</td>
</tr>
<tr>
<td>Park City</td>
<td>100</td>
<td>15</td>
<td>$100.00</td>
<td>$1,600.00</td>
</tr>
<tr>
<td>Solitude</td>
<td>202</td>
<td>30</td>
<td>$100.00</td>
<td>$6,160.00</td>
</tr>
<tr>
<td>Sundance</td>
<td>0</td>
<td>40</td>
<td>$100.00</td>
<td>$0.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>900</td>
<td></td>
<td></td>
<td>$14,679.80</td>
</tr>
</tbody>
</table>

**Shadow Price** = $14,679.80 - $14,739.80 = -$60.00

<table>
<thead>
<tr>
<th>Bus</th>
<th>Monitored Line</th>
<th>DFAX</th>
<th>Shadow Price</th>
<th>Congestion Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brighton</td>
<td>Brighton - Sundance</td>
<td>0.307167</td>
<td>-$60.00</td>
<td>-$18.43</td>
</tr>
<tr>
<td>Alta</td>
<td>Brighton - Sundance</td>
<td>0.199167</td>
<td>-$60.00</td>
<td>-$11.95</td>
</tr>
<tr>
<td>Park City</td>
<td>Brighton - Sundance</td>
<td>0.199167</td>
<td>-$60.00</td>
<td>-$11.95</td>
</tr>
<tr>
<td>Solitude</td>
<td>Brighton - Sundance</td>
<td>0</td>
<td>-$60.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Sundance</td>
<td>Brighton - Sundance</td>
<td>-0.16367</td>
<td>-$60.00</td>
<td>$9.82</td>
</tr>
</tbody>
</table>
## Example # 2 – Summary

<table>
<thead>
<tr>
<th>Unit</th>
<th>Offer Price</th>
<th>Penalty Factor</th>
<th>Adjusted Offer</th>
<th>System Energy Price</th>
<th>Loss Price</th>
<th>Congestion Price</th>
<th>Total LMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brighton</td>
<td>$10.00</td>
<td>1.0553</td>
<td>$10.5530</td>
<td>$30.00</td>
<td>-$1.57</td>
<td>-$18.43</td>
<td>$10.00</td>
</tr>
<tr>
<td>Alta</td>
<td>$14.00</td>
<td>1.0449</td>
<td>$14.6286</td>
<td>$30.00</td>
<td>-$1.29</td>
<td>-$11.95</td>
<td>$16.76</td>
</tr>
<tr>
<td>Park City</td>
<td>$15.00</td>
<td>1.0449</td>
<td>$15.6735</td>
<td>$30.00</td>
<td>-$1.29</td>
<td>-$11.95</td>
<td>$16.76</td>
</tr>
<tr>
<td>Solitude</td>
<td>$30.00</td>
<td>1.0000</td>
<td>$30.0000</td>
<td>$30.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$30.00</td>
</tr>
<tr>
<td>Sundance</td>
<td>$40.00</td>
<td>1.0161</td>
<td>$40.6440</td>
<td>$30.00</td>
<td>-$0.47</td>
<td>$9.82</td>
<td>$39.35</td>
</tr>
</tbody>
</table>

- **Marginal Unit**
- **Reference Bus**

<table>
<thead>
<tr>
<th>Unit Running</th>
<th>Unit Not Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>✅</td>
<td>✗</td>
</tr>
</tbody>
</table>

Loss and Congestion Components of LMP are “0” at the Reference Bus

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Agenda

• LMP Components
• 5 Bus Model
• Shadow Prices

• Statistics
• LMP Simulation Demo
### Table 3-75 Day-ahead and real-time average LMP (Dollars per MWh): 2001 through 2015

<table>
<thead>
<tr>
<th>Year</th>
<th>Day Ahead</th>
<th>Real Time</th>
<th>Difference</th>
<th>Percent of Real Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>$32.75</td>
<td>$32.38</td>
<td>($0.37)</td>
<td>(1.1%)</td>
</tr>
<tr>
<td>2002</td>
<td>$28.46</td>
<td>$28.30</td>
<td>($0.16)</td>
<td>(0.6%)</td>
</tr>
<tr>
<td>2003</td>
<td>$38.73</td>
<td>$38.28</td>
<td>($0.45)</td>
<td>(1.2%)</td>
</tr>
<tr>
<td>2004</td>
<td>$41.43</td>
<td>$42.40</td>
<td>$0.97</td>
<td>2.3%</td>
</tr>
<tr>
<td>2005</td>
<td>$57.89</td>
<td>$58.08</td>
<td>$0.18</td>
<td>0.3%</td>
</tr>
<tr>
<td>2006</td>
<td>$48.10</td>
<td>$49.27</td>
<td>$1.17</td>
<td>2.4%</td>
</tr>
<tr>
<td>2007</td>
<td>$54.67</td>
<td>$57.58</td>
<td>$2.90</td>
<td>5.3%</td>
</tr>
<tr>
<td>2008</td>
<td>$66.12</td>
<td>$66.40</td>
<td>$0.28</td>
<td>0.4%</td>
</tr>
<tr>
<td>2009</td>
<td>$37.00</td>
<td>$37.08</td>
<td>$0.08</td>
<td>0.2%</td>
</tr>
<tr>
<td>2010</td>
<td>$44.57</td>
<td>$44.83</td>
<td>$0.26</td>
<td>0.6%</td>
</tr>
<tr>
<td>2011</td>
<td>$42.52</td>
<td>$42.84</td>
<td>$0.32</td>
<td>0.7%</td>
</tr>
<tr>
<td>2012</td>
<td>$32.79</td>
<td>$33.11</td>
<td>$0.32</td>
<td>1.0%</td>
</tr>
<tr>
<td>2013</td>
<td>$37.15</td>
<td>$36.55</td>
<td>($0.60)</td>
<td>(1.6%)</td>
</tr>
<tr>
<td>2014</td>
<td>$49.15</td>
<td>$48.22</td>
<td>($0.93)</td>
<td>(1.9%)</td>
</tr>
<tr>
<td>2015</td>
<td>$34.12</td>
<td>$33.39</td>
<td>($0.73)</td>
<td>(2.1%)</td>
</tr>
</tbody>
</table>
Table 3-74 Day-ahead and real-time average LMP (Dollars per MWh): 2014 and 2015

<table>
<thead>
<tr>
<th></th>
<th>2014</th>
<th></th>
<th>Percent of Real Time</th>
<th>2015</th>
<th></th>
<th>Percent of Real Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day Ahead</td>
<td>Real Time</td>
<td>Difference</td>
<td>Day Ahead</td>
<td>Real Time</td>
<td>Difference</td>
</tr>
<tr>
<td>Average</td>
<td>$49.15</td>
<td>$48.22</td>
<td>($0.93)</td>
<td>(1.9%)</td>
<td>$34.12</td>
<td>$33.39</td>
</tr>
<tr>
<td>Median</td>
<td>$38.10</td>
<td>$34.46</td>
<td>($3.64)</td>
<td>(10.6%)</td>
<td>$29.09</td>
<td>$26.61</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>$51.88</td>
<td>$65.08</td>
<td>$13.20</td>
<td>20.3%</td>
<td>$22.59</td>
<td>$27.80</td>
</tr>
<tr>
<td>Peak average</td>
<td>$60.65</td>
<td>$59.12</td>
<td>($1.54)</td>
<td>(2.6%)</td>
<td>$40.97</td>
<td>$39.44</td>
</tr>
<tr>
<td>Peak median</td>
<td>$44.55</td>
<td>$40.50</td>
<td>($4.05)</td>
<td>(10.0%)</td>
<td>$33.69</td>
<td>$29.95</td>
</tr>
<tr>
<td>Peak standard deviation</td>
<td>$64.56</td>
<td>$81.78</td>
<td>$17.22</td>
<td>21.1%</td>
<td>$26.30</td>
<td>$30.23</td>
</tr>
<tr>
<td>Off peak average</td>
<td>$39.12</td>
<td>$38.72</td>
<td>($0.41)</td>
<td>(1.1%)</td>
<td>$28.11</td>
<td>$28.08</td>
</tr>
<tr>
<td>Off peak median</td>
<td>$31.37</td>
<td>$29.39</td>
<td>($1.98)</td>
<td>(6.7%)</td>
<td>$24.51</td>
<td>$23.62</td>
</tr>
<tr>
<td>Off peak standard deviation</td>
<td>$34.48</td>
<td>$43.64</td>
<td>$9.16</td>
<td>21.0%</td>
<td>$16.54</td>
<td>$24.28</td>
</tr>
</tbody>
</table>

83 The averages used are the annual average of the hourly average PJM prices for day-ahead and real-time.
Figure 3-41 PJM system hourly average LMP: 2015
Agenda

- LMP Components
- 5 Bus Model
- Shadow Prices
- Statistics
- LMP Simulation Demo
Questions?

PJM Client Management & Services
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Website: www.pjm.com

The Member Community is PJM’s self-service portal for members to search for answers to their questions or to track and/or open cases with Client Management & Services