Dispatch Signal & Locational Marginal Pricing (LMP)
Objectives

Students will be able to:

• Identify how PJM dispatches & utilizes LMP
Definition:
The **Dispatch Rate** is expressed in dollars per MWh, calculated and transmitted to each generator to direct the output level of all generation resources dispatched by PJM based on the incremental offer data which was previously received from the Generators.

**Dispatch Rate**

Where PJM wants

The units to be loaded economically
Dispatch Rate

The Dispatch Rate is determined by the PJM economic dispatch solution as calculated by PJM’s Security Constrained Economic Dispatch program (SCED).

The Economic Basepoint is the MW value sent to the generating unit that indicates to what level the unit should be loaded based on the economic dispatch solution and the units incremental price curve.

![Graph showing dispatch rate](image)

Dispatch Rate = $25
Transmission Losses

• Real Power (MW) Losses
  – Power flow converted to heat in transmission equipment
  – Heat produced by current (I) flowing through resistance (R)
  – Losses equal to $I^2R$
  – Heat loss sets the “thermal rating” of equipment

\[
\text{Heat Disipated} = I^2R
\]
Transmission Losses

• Real Power (MW) Losses
  – Increase with line length
    • Increased R
  – Increase with increased current flow (I)
  – Increase at lower voltages
    • Higher currents

\[ \text{Transmission Losses} = \text{Power} = \text{Current} \times \text{Voltage} \]
Transmission Losses

Power In: 100 MW
Voltage In: 235 KV
Current In: 425.53 A

Power Out: 90.946 MW
Voltage Out: 213.72 KV
Current Out: 425.53 A

Power Loss: 9.054 MW
Power In: 100 MW
Voltage In: 235 KV
Current In: 425.53 A

Power Out: 98.2 MW
Voltage out: 230.74 KV
Current Out: 425.53 A

Power Loss: 1.8 MW
The Incremental Loss for bus $i$ is used to calculate a factor that can be used to include the effect of losses in the dispatch.

This factor is called the Loss Penalty Factor, or Penalty Factor.

The Penalty Factors adjust the incremental cost of each generator so as to include the effects of losses.

Penalty factors applied to each and every location:
- Including generation, load, virtual transaction.

\[
Pf_i = \frac{1}{1 - \frac{\Delta P_L}{\Delta P_i}}
\]

Change in Losses
Change in Unit’s MW Output
Penalty Factors Effect on Dispatch

• If an increase in generation results in an increase in system losses then:
  – Penalty factor is greater than 1
  – Units offer curve is adjusted higher
    • Unit offer curve is multiplied by penalty factor
    • Unit looks less attractive to dispatch

Loss Factor

\[ 0 < \frac{\Delta P_L}{\Delta P_i} < 1 \]

Increase in injection will result in higher overall system losses

Penalty Factor

\[ Pf_i = \frac{1}{1 - \frac{\Delta P_L}{\Delta P_i}} > 1.0 \]
If an increase in generation results in a decrease in system losses then:

- Penalty factor is less than 1
- Units offer curve is adjusted lower
  - Unit offer curve is multiplied by penalty factor
  - Unit looks more attractive to dispatch
  - Total LMP would still at least equal unit’s original offer

\[
\text{Loss Factor} \quad 0 > \frac{\Delta P_L}{\Delta P_i} > -1
\]

Increase in injection will result in lower overall system losses

\[
\text{Penalty Factor} \quad Pf_i = \frac{1}{1 - \frac{\Delta P_L}{\Delta P_i}} < 1.0
\]
Penalty Factors Effect on Dispatch - Example # 1

<table>
<thead>
<tr>
<th>Generating Unit # 1</th>
<th>Generating Unit # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Offer Price</strong></td>
<td><strong>Offer Price</strong></td>
</tr>
<tr>
<td>$10.00 ----- 200 MW</td>
<td>$10.00 ----- 200 MW</td>
</tr>
<tr>
<td>$20.00 ----- 300 MW</td>
<td>$20.00 ----- 300 MW</td>
</tr>
<tr>
<td>$30.00 ----- 400 MW</td>
<td>$30.00 ----- 400 MW</td>
</tr>
<tr>
<td>$40.00 ----- 500 MW</td>
<td>$40.00 ----- 500 MW</td>
</tr>
<tr>
<td><strong>Generating 300 MW</strong></td>
<td><strong>Generating 305 MW</strong></td>
</tr>
<tr>
<td>Penalty Factor = 1.00</td>
<td>Penalty Factor = 0.97</td>
</tr>
<tr>
<td>$20 * 1.00 = $20.00</td>
<td>$20.50 * 0.97 = $19.89</td>
</tr>
</tbody>
</table>
Generation Redispatch

For Contingency Analysis
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
Contingency Analysis

Contingency Analysis

• “What if" scenario simulator that evaluates, provides and prioritizes the impacts on an electric power system when problems occur.
  – A contingency is a provision for an unforeseen event or circumstance
    • Loss or failure of a small part of the power system (e.g. a transmission line)
    • Loss or failure of individual equipment such as a generator or transformer

• Computer application that uses a simulated model of the power system
  – Evaluates the effects of an outage event
  – Calculates any overloads that may result

• This is referred to as maintaining system security
How Contingency Analysis Works

- Executes a power flow analysis for each potential problem that is defined on a contingency list
  - A contingency list contains each of the elements that will be removed from the network model, one by one, to test the effects for possible overloads of the remaining elements
  - The failure or outage of each element in the contingency list is simulated in the network model by removing that element
  - The resulting network model is solved to calculate the resulting power flows, voltages, and currents for the remaining elements of the model
• Review available controlling actions and the distribution factor (DFAX) effect on the overloaded facility.
  – Consider whether there are sufficient resources available to control transmission facilities within acceptable limits.

• Initiate off-cost if reasonable controlling actions are available
Real Time Contingency Operations

- The $/MW effect on a transmission line is used to determine which units should be redispatched in constrained situations

- $/MW Effect = (System Marginal Price – Marginal Cost of Unit)/Unit Shift Factor
  - SMP and Marginal Cost of Unit values are the result of optimization

- Units with lowest $/MW effect are used to redispatched when the system is constrained

- Other unit parameters are taken into account (i.e. eco min, eco max, min run time, etc.)
LMP Basics
What is LMP?

• Locational Marginal Price

• 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

• Physical, flow-based pricing system:
  – how energy actually flows, NOT contract paths
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
**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
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
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
LMP Components - System Energy Price

Installed = 2,000 MW

Dispatch 1500 MW

System Energy Price = $20
Congestion =
Losses =
LMP = $20

Transmission Path

Load = 1500 MW

System Energy Price = $20
Congestion =
Losses =
LMP = $20

Installed = 700 MW

$20 Power

$50 Power
LMP Components - Congestion

Installed = 2,000 MW

**Dispatch 1000 MW**

$20 Power

- **Flow** = 1000 MW
- **Limit** = 1000 MW

<table>
<thead>
<tr>
<th>Installed = 2000 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System Energy Price</strong> = $20</td>
</tr>
<tr>
<td><strong>Congestion</strong> = $0</td>
</tr>
<tr>
<td><strong>Losses</strong> =</td>
</tr>
<tr>
<td><strong>LMP</strong> = $20</td>
</tr>
</tbody>
</table>

**Load = 1500 MW**

$50 Power

<table>
<thead>
<tr>
<th>Dispatch 500 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System Energy Price</strong> = $20</td>
</tr>
<tr>
<td><strong>Congestion</strong> = $30</td>
</tr>
<tr>
<td><strong>Losses</strong> =</td>
</tr>
<tr>
<td><strong>LMP</strong> = $50</td>
</tr>
</tbody>
</table>

Install = 700 MW

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LMP Components Marginal Losses

Installed = 2,000 MW

Dispatch 1010 MW

System Energy Price = $20
Congestion = $0
Losses = ($1)
LMP = $19

Flow = 1000 MW
Limit = 1000 MW

Load 1500 MW

$20 Power

Dispatch 520 MW

System Energy Price = $20
Congestion = $30
Losses = $2
LMP = $52

$50 Power

Installed = 700 MW

Note: assume 2% (30mw) losses – allocation of losses in this example are theoretical
Losses on a real system are optimized based on system topology
Questions?

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