ERCOT Market Education

Resource 301

Module 5: Resources in Real-Time Operations
Topics in this module ...

- Real-Time Dispatch Overview and Formation of Dispatch Limits
- The Mind of SCED (Security Constrained Economic Dispatch)
- Load Frequency Control and Primary Frequency Response
- Provision and Deployment of Ancillary Services
- Real-Time Settlements
Real-Time Dispatch Overview & Formation of Dispatch Limits
SCED requires multiple inputs

- Telemetry
- Network Operations Model
- Contingencies

Real-Time Dispatch

Real-Time Network Security Analysis

Security-Constrained Economic Dispatch

- Offers
- Pricing
- Dispatch Instructions
Security Analysis provides Transmission Constraints

Transmit Constraints

Real-Time Dispatch

Offers

Constraints & Shift Factors

Security-Constrained Economic Dispatch

Network Operations Model

Telemetry

Contingencies

Pricing

Dispatch Instructions
Resource Dispatch Limits

Resource Limit Calculator determines Dispatch Limits

- Telemetry
- Network Operations Model
- Contingencies

Real-Time Dispatch

- Resource Limit Calculator
- Constraints & Shift Factors

Security-Constrained Economic Dispatch

- Offers

- Pricing
- Dispatch Instructions
Dispatch Limits for Generation Resources

High Sustained Limit

Low Sustained Limit

Telemetered by the QSE

Operating Point

HSL

LSL
High Sustained Limit

Telemetered by the QSE
- AS Schedule (RRS & Non-Spin)
- AS Resource Responsibility (Reg)

Low Sustained Limit
High Ancillary Service Limit

= HSL – Reg-Up Responsibility
  – RRS Schedule
  – Non-Spin Schedule

Low Ancillary Service Limit

= LSL – Reg-Down Responsibility
Dispatch Limits for Generation Resources

**SCED Up Ramp Rate (SURAMP)**

\[ \text{SCED Up Ramp Rate} = \text{Up Ramp Rate} - (1 - \text{RDSDEPLP}) \times (\text{Reg-Up Resp} / 7) \]

\[ \text{Reg-up Deployment Percentage} \]

**SCED Down Ramp Rate (SDRAMP)**

\[ \text{SCED Down Ramp Rate} = \text{Down Ramp Rate} - (1 - \text{RUSDEPLP}) \times (\text{Reg-Down Resp} / 7) \]

\[ \text{Reg-down Deployment Percentage} \]
High Dispatch Limit

HDL = Operating Point + (SURAMP * 5)

\[ \text{HDL} \leq \text{HASL} \]

Low Dispatch Limit

LDL = Operating Point – (SDRAMP * 5)

\[ \text{LDL} \geq \text{LASL} \]
Example 1: Dispatch Limits for Generation Resource

Generator is “ON” with current operating point of 150MW

Ramp Rates:
- Normal Up = 3MW/min
- Normal Down = 4MW/min

What are HDL and LDL?

\[
\text{HDL} = \text{Operating Point} + (\text{Ramp Rate} \times \text{Ramp Duration}) = 150\text{MW} + (3\text{MW/min} \times 5\text{min}) = 165\text{MW}
\]

\[
\text{LDL} = \text{Operating Point} - (\text{Ramp Rate} \times \text{Ramp Duration}) = 150\text{MW} - (4\text{MW/min} \times 5\text{min}) = 130\text{MW}
\]
Example 2: Dispatch Limits for Generation Resource

Generator is “ONREG” with current operating point of 150MW

- **HSL**
- **HASL**
- **HDL**
- **LDL**
- **LSL**

**Ramp Rates:**
- Normal Up = 3MW/min
- Normal Down = 4MW/min

**Reg-Down deployment percentage = 50%**

**What is HDL?**

\[ HDL = 150MW + (SURAMP \times 5 \text{ min}) \]

\[ \text{SURAMP} = 3\text{MW/min} - (1 - 0.50) \times \left( \frac{14\text{MW}}{7\text{min}} \right) = 2\text{MW/min} \]

\[ HDL = 150\text{MW} + (2\text{MW/min} \times 5 \text{ min}) = 160\text{MW} \]
Example 3: Dispatch Limits for Generation Resource

Generator is “ONREG” with current operating point of 150MW

HSL

Ramp Rates:
- Normal Up = 3MW/min
- Normal Down = 4MW/min

HASL

Reg-Up deployment percentage = 0%

HDL

What is LDL?

LDL

21MW Reg-Down

5 minutes

10 MW Reg-Up

SURAMP

Operating Point

SDRAMP

21MW Reg-Down

5 minutes
SCED must also have a Power Balance Constraint
Offers allow SCED to achieve economic dispatch

- Telemetry
- Network Operations Model
- Contingencies

Real-Time Dispatch

- Resource Limit Calculator
- Constraints & Shift Factors
- Generation to be Dispatched

Security-Constrained Economic Dispatch

- Pricing
- Dispatch Instructions
Submitted for:

- Resources currently online
- Quick Start Generation Resources (QSGRs)

Expected to span LSL to HSL
Alternate “Offer” for a Generation Resource:

- Specifies desired output for each five-minute interval
- Price taker at specified output level
Real-Time Market Energy Bid

“Offer” for Load Resources dispatched by SCED:

May be submitted for:

- Qualified Controllable Load Resources
- Charging load for Energy Storage Resource

Expected to span LSL to HSL
The Mind of SCED
SCED Objective

- Dispatch Resources at minimum cost
- Subject to various constraints
  - Security constraints
    - Power Balance Constraint
    - Transmission Constraints
  - Resource Dispatch Limits
Minimize:

\[ \text{Energy Costs} + \text{Penalty Costs} \]

Penalty Costs include:

- Cost for violating Power Balance Constraint
- Cost for violating a Transmission Constraint
SCED optimization calculates Shadow Prices

- $SP_{\text{demand}}$ for the power balance constraint
- $SP_{c}$ for each transmission constraint

Penalty costs achieved through Shadow Price Caps

- Power Balance Penalty is maximum limit of $SP_{\text{demand}}$
- Each Transmission constraint has a max $SP_{c}$
Power Balance Penalty

<table>
<thead>
<tr>
<th>MW Violation</th>
<th>$/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW ≤ 5</td>
<td>250</td>
</tr>
<tr>
<td>5 &lt; MW ≤ 10</td>
<td>300</td>
</tr>
<tr>
<td>10 &lt; MW ≤ 20</td>
<td>400</td>
</tr>
<tr>
<td>20 &lt; MW ≤ 30</td>
<td>500</td>
</tr>
<tr>
<td>30 &lt; MW ≤ 40</td>
<td>1000</td>
</tr>
<tr>
<td>40 &lt; MW ≤ 50</td>
<td>2250</td>
</tr>
<tr>
<td>50 &lt; MW ≤ 100</td>
<td>4500</td>
</tr>
<tr>
<td>100 &lt; MW ≤ 150</td>
<td>6000</td>
</tr>
<tr>
<td>150 &lt; MW ≤ 200</td>
<td>7500</td>
</tr>
<tr>
<td>200 &lt; MW</td>
<td>9001</td>
</tr>
</tbody>
</table>

Under-Generation

<table>
<thead>
<tr>
<th>MW Violation</th>
<th>$/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW &lt; 100,000</td>
<td>-250</td>
</tr>
</tbody>
</table>

Over-Generation
Any Power Balance violation by SCED will be covered by Regulation.
## Penalty for Violating Transmission Constraint

### Shadow Price Caps

<table>
<thead>
<tr>
<th>Type of Violation</th>
<th>Voltage</th>
<th>$/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case / Voltage</td>
<td>N/A</td>
<td>9251</td>
</tr>
<tr>
<td>N-1 Constraint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>69kV</td>
<td></td>
<td>2800</td>
</tr>
<tr>
<td>138kV</td>
<td></td>
<td>3500</td>
</tr>
<tr>
<td>345kV</td>
<td></td>
<td>4500</td>
</tr>
</tbody>
</table>

Cost for violating constraint depends on
- Shadow Price Cap
- MW violation amount
Determining Locational Marginal Prices for Energy

$$LMP_{bus} = SP_{demand} - \sum_{c} SF_{bus,c} \ast SP_{c}$$

Shift Factor of the bus on Transmission Constraint “c”

Also known as System Lambda (λ)

... Any of these Shadow Prices may be set by a cap
A Generation Resource is available for SCED dispatch

SCED runs at 1100 and dispatches the Resource to 80MW @$43.

SCED runs at 1105 and dispatches Resource to 55MW @ -$1000

What is happening?
Load Frequency Control & Primary Frequency Response
Load Frequency Control
• Maintains system frequency, by
• Increasing/decreasing real power output of Resources,
• Without cost optimization

Primary Frequency Response
• Stabilizes system frequency, by
• Increasing/decreasing real power output system-wide
• Without cost optimization

... so what are the differences?
Governor Control Systems
The following units must have Governor systems:

- Generation Resources
- Settlement Only Transmission Generators
- Settlement Only Transmission Self-Generators
- Controllable Load Resources
Governors must respond to changes in system frequency

. . . after a point
Control of System Frequency

System Frequency (Hz)

Time (seconds)
System Frequency Control between Governor Deadbands

Between Deadbands:
- No governor response
- Load Frequency Control manages frequency

<table>
<thead>
<tr>
<th>Time (seconds)</th>
<th>System Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>59.983</td>
</tr>
<tr>
<td>50</td>
<td>60.000</td>
</tr>
<tr>
<td>100</td>
<td>60.017</td>
</tr>
<tr>
<td>150</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>60.000</td>
</tr>
</tbody>
</table>

Governor Deadband

- Governor Deadband: 59.983 Hz to 60.017 Hz
System Frequency Control outside Governor Deadbands

Outside Deadbands:
• Load Frequency Control
• Governor response as capable
## Governor Droop and Deadband Settings

### Max. Droop

<table>
<thead>
<tr>
<th>Generator Type</th>
<th>Max. Droop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Cycle Combustion Turbines</td>
<td>4%</td>
</tr>
<tr>
<td>All Other Generating Units, Generating Facilities and CLRs</td>
<td>5%</td>
</tr>
</tbody>
</table>

### Max. Deadband

<table>
<thead>
<tr>
<th>Generator Type</th>
<th>Max. Deadband</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam or Hydro Turbines with Mechanical Governors</td>
<td>+/- 0.034 Hz</td>
</tr>
<tr>
<td>All Other Generating Units and Generating Facilities</td>
<td>+/- 0.017 Hz</td>
</tr>
<tr>
<td>Controllable Load Resources (CLRs)</td>
<td>+/- 0.036 Hz</td>
</tr>
</tbody>
</table>
Primary Frequency Response (PFR)

Each Resource must provide proportional response

- When frequency is high

\[
PFR = \frac{\Delta \text{freq} - \text{Generator Deadband}}{\text{Droop} \times 60 - \text{Generator Deadband}} \times (-1) \times \text{HSL}
\]

- When frequency is low

\[
PFR = \frac{\text{Generator Deadband} - \Delta \text{freq}}{\text{Droop} \times 60 - \text{Generator Deadband}} \times (-1) \times \text{HSL}
\]

For IRRs, HSL is current capability.
Example: Governor System Response

Primary Frequency Response

System Frequency reaches 60.02 Hz

Wind Generation Resource Dusty Mesa has HSL of 100MW, based on current conditions.

What is Dusty Mesa’s expected Primary Frequency Response?
System Frequency Control – Ramping Suspension

± 0.05Hz Thresholds:
- Load Frequency Control
- Governor response
- Suspend ramping that harms frequency
Ramping Suspension – Updated Desired Base Point

Ramping Suspended through Updated Desired Base Point (UDBP)
Updated Desired Base Point

• 4 second ICCP signal

• Expected MW output of a ramping Resource
  • Calculated to reach Base Point in 240 seconds
  • Does not include Regulation Deployments
Provision and Deployment of Ancillary Services
Topics in this Section Include

1. Operational Requirements for Ancillary Services
2. Resource Limits by Ancillary Service Product
3. Ancillary Service Deployment Methodologies
Provides capacity used to maintain system frequency

<table>
<thead>
<tr>
<th>Regulation Service Products</th>
<th>General Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation Up</td>
<td>Respond within 5 sec</td>
</tr>
<tr>
<td>Regulation Down</td>
<td></td>
</tr>
<tr>
<td>Fast Responding Regulation Up</td>
<td>Responds within 60 cycles of ERCOT signal</td>
</tr>
<tr>
<td></td>
<td>-or-</td>
</tr>
<tr>
<td></td>
<td>By frequency trigger (+/- 0.09Hz)</td>
</tr>
<tr>
<td>Fast Responding Regulation Down</td>
<td></td>
</tr>
</tbody>
</table>

Must be capable of ramping through reserved capacity in 5 minutes
Responsive Reserve Service

Provides capacity reserves to:

• Respond to significant frequency deviations
• Serve as backup Regulation Up
• Provide additional capacity during an Energy Emergency Alert (EEA)

Must be capable of ramping through reserved capacity in 10 minutes
Provides additional reserves with longer lead time

- Must be capable of running at a specified output level for at least one hour
- May be used for system-wide or local needs

Must be capable of ramping through reserved capacity in 30 minutes
### Who carries what?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Controllable Load Resource</td>
<td>Controllable Load Resource</td>
<td>On-line Generation Resource</td>
</tr>
<tr>
<td></td>
<td>Energy Storage Resource</td>
<td></td>
</tr>
</tbody>
</table>
Topics in this Section Include

1. Operational Requirements for Ancillary Services
2. Resource Limits by Ancillary Service Product
3. Ancillary Service Deployment Methodologies
**The following Resource limits are enforced in Real-Time:**

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>Resource Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-line Generation Resources</td>
<td>Responsive Reserve $\leq 20%$ HSL</td>
</tr>
<tr>
<td></td>
<td>and $\leq 10 \times$ Emergency Ramp Rate</td>
</tr>
<tr>
<td>Off-Line Generation Resources</td>
<td>Non-Spin Reserve $\leq$ HSL</td>
</tr>
<tr>
<td>Hydro Resource as Synchronous Condenser</td>
<td>Responsive Reserve $\leq$ 20 second capability</td>
</tr>
<tr>
<td>All On-line Resources</td>
<td>LSL + Responsive + Regulation + Non-Spin $\leq$ HSL</td>
</tr>
</tbody>
</table>
The following system limits are enforced in Real-Time:

<table>
<thead>
<tr>
<th>Ancillary Service</th>
<th>System Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast Responding Regulation Up</td>
<td>System total may not exceed 65 MW</td>
</tr>
<tr>
<td>Fast Responding Regulation Down</td>
<td>System total may not exceed 35 MW</td>
</tr>
<tr>
<td>Responsive Reserve</td>
<td>Load Resources on UFR may not exceed</td>
</tr>
<tr>
<td></td>
<td>• 60% of ERCOT Responsive Reserve Reserve requirement</td>
</tr>
<tr>
<td></td>
<td>• 60% of QSE’s Self arranged Responsive Reserve Obligation</td>
</tr>
</tbody>
</table>
Topics in this Section Include

1. Resource Limits by Ancillary Service Product
2. Ancillary Service Deployment Methodologies
Load Frequency Control (LFC)

• Responds to frequency deviations

• Deploys certain Ancillary Services
  • Regulation Up
  • Regulation Down
  • Responsive Reserve

• Provides Updated Desired Base Point
Regulation Service

Provides capacity that can respond to signals from ERCOT in order to maintain system frequency

- Deployed proportionally by QSE’s share of Regulation provided
- QSE chooses how to distribute across their Resources

*But how does LFC know how much Regulation to Deploy?*
ERCOT Area Control Error (ACE) is the MW-equivalent correction needed to control the actual system frequency to the scheduled system frequency value.

The Equation

\[
\text{ERCOT ACE} = -10\beta (F_S - F_A)
\]

Adjusted for difference between Resources’ UDBP and actual MW output

<table>
<thead>
<tr>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_S )</td>
</tr>
<tr>
<td>( F_A )</td>
</tr>
<tr>
<td>( \beta )</td>
</tr>
</tbody>
</table>
Area Control Error

Regulate Down when ACE > 0

Regulate Up when ACE < 0
Regulation Service Communications

QSEs to ERCOT:
- AS Resource Responsibility
- Participation Factors
- Raise/Lower Block Status

ERCOT to QSEs:
- Regulation MW
- Fast Responding Regulation MW
Participation Factors

- Separate values for Regulation-Up and Regulation-Down
- Used to calculate what remains on each Resource
- Used in Base Point Deviation Settlement
Raise Block Status and Lower Block Status

- Indicate that Resource is temporarily unable to respond
- Set only until Resource limits and/or Ancillary Service telemetry can be updated
- Reduces QSE’s overall Regulation deployment
Two modes of Deployment

• By ERCOT Regulation Control Signal
  • ERCOT determines MW deployment
  • Resource must deploy to specified level in 60 cycles

• By Frequency Trigger
  • Resource auto deploys at +/- 0.09 Hz
  • Resource must deploy 100% within 60 cycles of trigger

In either case, ERCOT will recall when system frequency recovers.
Responsive Reserve Service

Used under normal operations to recover from significant frequency deviations

Multiple modes of deployment

- Manual
  - ICCP Control Signal
  - XML Message (Load Resources)
- Frequency Triggers
Responsive Reserve Service

Used under normal operations to recover from significant frequency deviations

Frequency Triggers

- 59.85 – Fast Frequency Response (FFR) within 15 cycles
- 59.7 Hz – Load Resources on Under Frequency Relay trip within 30 cycles
Responsive Reserve Service Deployment

Responsive Reserve Communications

QSEs to ERCOT:
- AS Resource Responsibility
- AS Schedule

ERCOT to QSEs:
- Responsive Reserve MW
- Resource Base Point MW
Responsive Reserve Deployment

QSE Control Systems <-> ICCP <-> ERCOT Systems

- QSE reduces AS Schedules Within 1 minute
- ERCOT triggers SCED to dispatch Resources
Class Activity

Name that Frequency!

Summary of Frequency Triggers

Let's summarize all the frequency triggers we've introduced. Take a few minutes to look over your notes and then we'll discuss as a class.

- Suspend Ramping through UDBP
- FRRS Down Deploys Automatically
- FRRS Up Deploys Automatically
- Load Resources on UFR trip
- ERCOT shall go immediately to EEA Level 3
- FFR Deploys Automatically
Non-Spinning Reserve Service

Provides additional capacity reserves that can be utilized within 30 minutes

**Uses**

- System-Wide capacity shortage
- Local capacity shortage
- Recover Responsive Reserve Service in a timely manner
Off-Line Generation Resource

- Deployed by Operator Dispatch Instruction
  - Always 100% of individual Resource Responsibility
  - Deployed in economic order
- QSE responsibilities
  - Non-Spin Schedule set to zero within 20 minutes
  - Resource dispatchable by SCED within 25 minutes
On-Line Generation Resource

- Standing Deployment During Operating Hour
  - Non-Spin Schedule = 0
  - Non-Spin Responsibility priced at or above $75

- SCED dispatches Non-Spin capacity as economics dictate
Non-Spinning Reserve Service Deployment

Non-Frequency Responsive Capacity (NFRC) from power augmentation

- Deployed by Operator Dispatch Instruction
- QSE responsibilities
  - Non-Spin Schedule = Power Augmentation MW
  - Non-Spin Schedule = 0 within 20 minutes of deployment
On-Line Non-Spin with other Ancillary Services

- The following products must also be priced at or above $75
  - Regulation Up
  - Responsive Reserve
  - NFRC
Real-Time Settlements
Topics in this Section Include

1. Real-Time Energy Imbalance
2. Settlement of RUC-Committed Resources
Real-Time Energy Imbalance Equation at a Resource Node:

\[
\begin{align*}
-1 \left( \left( \text{DAM Energy Purchases} + \text{Trade Energy Purchases} \right) - \left( \text{DAM Energy Sales} + \text{Trade Energy Sales} \right) \right) \times \text{RTSPP} \\
+ (-1) \left( \text{Metered Generation} \right) \times \text{RTRMPR}
\end{align*}
\]
At a Resource Node,

**RTSPP** is used to settle financial transactions

\[
\text{RTSPP} = \text{RTRSVPOR} + \text{RTRDP} + \text{Time-Weighted Average} \left( \text{LMPs} \right)
\]

<table>
<thead>
<tr>
<th>RTSPP</th>
<th>Real-Time Settlement Point Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTRSVPOR</td>
<td>Real-Time Reserve Price for On-Line Reserves</td>
</tr>
<tr>
<td>RTRDP</td>
<td>Real-Time On-Line Reliability Deployment Price</td>
</tr>
</tbody>
</table>
At a Resource Node,

**RTRMPR** is used to settle physical energy production

\[
RTRMPR = RTRSVPOR + RTRDP + \left( \text{Base-Point} \times \text{Time} \right) \text{Weighted Average LMPs}
\]

<table>
<thead>
<tr>
<th>RTRMPR</th>
<th><strong>Real-Time Resource Meter Price</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>RTRSVPOR</td>
<td><strong>Real-Time Reserve Price for On-Line Reserves</strong></td>
</tr>
<tr>
<td>RTRDP</td>
<td><strong>Real-Time On-Line Reliability Deployment Price</strong></td>
</tr>
</tbody>
</table>
Scenario 1: Real-Time Resource Settlements

**Generation Resource BIGGEN1 was awarded in DAM and runs in Real-Time**

- Awarded 80MW each hour for Hours 1 - 4
- On-line and dispatched in Real-Time during Hours 1 - 4

<table>
<thead>
<tr>
<th>Hour 1</th>
<th>RTRMPR</th>
<th>RTSPP</th>
<th>MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0015</td>
<td>19</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>0030</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>0045</td>
<td>22</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>0100</td>
<td>23</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>84</td>
</tr>
</tbody>
</table>

Energy Offer Curve

<table>
<thead>
<tr>
<th>MW</th>
<th>$ / MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>120</td>
<td>27</td>
</tr>
<tr>
<td>140</td>
<td>33</td>
</tr>
<tr>
<td>150</td>
<td>60</td>
</tr>
</tbody>
</table>
Scenario 1: Real-Time Resource Settlements

Real-Time Energy Imbalance for Interval 0015:

\[-1 \left( \left( \text{DAM Energy Purchases} + \text{Trade Energy Purchases} \right) - \left( \text{DAM Energy Sales} + \text{Trade Energy Sales} \right) \right) \times \text{RTSPP} + \left( -1 \right) \left( \text{Metered Generation} \right) \times \text{RTRMPR} \]

Which simplifies and re-arranges to . . .

\[-1 \left( \text{Metered Generation} \times \text{RTRMPR} \right) - \left( \text{DAM Energy Sales} + \text{Trade Energy Sales} \right) \times \text{RTSPP} \]
Real-Time Energy Imbalance for Interval 0015:

\[
(-1) \times \left( \text{Metered Generation} \times \text{RTRMPR} - \left( \text{DAM Energy Sales} + \text{Trade Energy Sales} \right) \times \text{RTSPP} \right)
\]

\[
(-1) \times \left( 18 \text{ MWh} \times $19/\text{MWh} - 20 \text{ MWh} \times $18/\text{MWh} \right) = $18
\]
Scenario 1: Real-Time Resource Settlements

Real-Time Energy Imbalance for Interval 0045:

\[
(-1) \times \left[ \text{Metered Generation} \times \text{RTRMPR} - \left( \text{DAM Energy Sales} + \text{Trade Energy Sales} \right) \times \text{RTSPP} \right]
\]

\[
(-1) \times \left[ 22 \text{ MWh} \times $22/\text{MWh} - 20 \text{ MWh} \times $21/\text{MWh} \right] = -$64
\]
Scenario 1: Real-Time Resource Settlements

Real-Time Revenues across all hours

- On-line and dispatched in Real-Time during Hours 1 - 4
- Assume Responsive Reserve was never deployed

<table>
<thead>
<tr>
<th>Hour</th>
<th>Real-Time Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 1</td>
<td>$158</td>
</tr>
<tr>
<td>Hour 2</td>
<td>$200</td>
</tr>
<tr>
<td>Hour 3</td>
<td>$225</td>
</tr>
<tr>
<td>Hour 4</td>
<td>$250</td>
</tr>
<tr>
<td>Total</td>
<td>$833</td>
</tr>
</tbody>
</table>

Is that all the revenue for BIGGEN1?
BIGGEN1 was also awarded Energy and Responsive Reserve in DAM

- Energy Award: 80MW @ $20 for Hours 1 - 4
- Responsive Reserve Award: 10MW @ $10 for Hours 1 - 4
- Make-Whole payment of $1075 per hour

<table>
<thead>
<tr>
<th></th>
<th>Real-Time Revenue</th>
<th>DAM Revenue</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 1</td>
<td>$158</td>
<td>$2775</td>
<td>$2993</td>
</tr>
<tr>
<td>Hour 2</td>
<td>$200</td>
<td>$2775</td>
<td>$2975</td>
</tr>
<tr>
<td>Hour 3</td>
<td>$225</td>
<td>$2775</td>
<td>$3000</td>
</tr>
<tr>
<td>Hour 4</td>
<td>$250</td>
<td>$2775</td>
<td>$3025</td>
</tr>
<tr>
<td>Total</td>
<td>$833</td>
<td>$11,100</td>
<td>$11,993</td>
</tr>
</tbody>
</table>
Scenario 2: Real-Time Resource Settlements

QSE schedules trades on BIGGEN1 and runs in Real-Time

- Startup Cost: $3000
- Minimum Energy Cost: $30/MWh
- LSL = 50 MW
QSE schedules trades on BIGGEN1 and runs in Real-Time

- 100MW in trades at the BIGGEN Resource Node for Hours 15 - 18
- QSE Starts Resource for Hour 15 and runs through Hour 18

<table>
<thead>
<tr>
<th>Hour 15</th>
<th>RTRMPR</th>
<th>RTSPP</th>
<th>MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1415</td>
<td>27</td>
<td>27</td>
<td>30</td>
</tr>
<tr>
<td>1430</td>
<td>29</td>
<td>28</td>
<td>31</td>
</tr>
<tr>
<td>1445</td>
<td>31</td>
<td>30</td>
<td>33</td>
</tr>
<tr>
<td>1500</td>
<td>34</td>
<td>33</td>
<td>35</td>
</tr>
</tbody>
</table>

Total 129

Energy Offer Curve

$ / MWh

MW

50 80 120 140 150

60 33 27 20 15
Scenario 2: Real-Time Resource Settlements

Real-Time Energy Imbalance for Interval 1415:

\[
(-1) \left(\text{Metered Generation} \times \text{RTRMPR} - \left(\text{DAM Energy Sales} + \text{Trade Energy Sales}\right) \times \text{RTSPP}\right)
\]

\[
(-1) \left(30 \text{ MWh} \times 27/\text{MWh} - 25 \text{ MWh} \times 27/\text{MWh}\right) = -135
\]
Scenario 2: Real-Time Resource Settlements

QSE schedules trades on BIGGEN1 and runs in Real-Time

- 100MW in trades at the BIGGEN Resource Node for Hours 15 - 18
- QSE Starts Resource for Hour 15 and runs through Hour 18

Is this Real-Time Revenue sufficient for BIGGEN1?

<table>
<thead>
<tr>
<th>Hour 14</th>
<th>$300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 15</td>
<td>$972</td>
</tr>
<tr>
<td>Hour 16</td>
<td>$1122</td>
</tr>
<tr>
<td>Hour 17</td>
<td>$1275</td>
</tr>
<tr>
<td>Hour 18</td>
<td>$802</td>
</tr>
<tr>
<td>Hour 19</td>
<td>$406</td>
</tr>
<tr>
<td>Total</td>
<td>$4877</td>
</tr>
</tbody>
</table>
Topics in this Section Include

1. Real-Time Energy Imbalance
2. Settlement of RUC-Committed Resources
Scenario 3: RUC-Related Settlements

Generation Resource BIGGEN1 is committed by RUC

- Startup Offer: $3000
- Minimum-Energy Offer: $30/MWh
- LSL = 50 MW

![Energy Offer Curve](image-url)
**Scenario 3: Real-Time Resource Settlements**

**Generation Resource BIGGEN1 is committed by RUC**

- Committed for Hours 7 - 10
- QSE Starts Resource and ramps to LSL by 0600

### Energy Offer Curve

<table>
<thead>
<tr>
<th>Hour 7</th>
<th>RTRMPR</th>
<th>RTSPP</th>
<th>MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0615</td>
<td>20</td>
<td>20</td>
<td>12.5</td>
</tr>
<tr>
<td>0630</td>
<td>20</td>
<td>20</td>
<td>12.5</td>
</tr>
<tr>
<td>0645</td>
<td>20</td>
<td>20</td>
<td>12.5</td>
</tr>
<tr>
<td>0700</td>
<td>20</td>
<td>20</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

**Total 50**
Scenarios 3: Real-Time Resource Settlements

Real-Time Energy Imbalance for Interval 0615:

\[
\begin{align*}
(-1) \times \left[ \text{Metered Generation} \times \text{RTRMPR} - \left( \text{DAM Energy Sales} + \text{Trade Energy Sales} \right) \times \text{RTSPP} \right]
\end{align*}
\]

\[
\begin{align*}
(-1) \times \left[ 12.5 \text{ MWh} \times $20/\text{MWh} - 0 \times $20/\text{MWh} \right] = -$250
\end{align*}
\]

At this rate, will they recover their Startup and Minimum-Energy Costs?
What if revenues are less than costs?

- Real-Time Revenue less Incremental Costs
- Costs Incurred
  - Startup Costs
  - Minimum-Energy Costs
  - RUC Guaranteed Amount
What if revenues are less than costs?

- **Make-Whole Payment**
- **Real-Time Revenue less Incremental Costs**
- **Minimum-Energy Costs**
- **Startup Costs**
Costs to be made whole:

- Look to Three-Part Supply Offer for cost data
- Capped at Verifiable Costs if available
- Otherwise, capped at Generic Costs
Which costs are eligible?

- Must actually incur the costs
- Minimum-Energy Costs included for RUC hours the Resource actually runs
- Startup costs included for starts incurred due to the RUC instruction
Startup Cost Eligibility

• One Start per contiguous block of committed hours
• QSE initially commits
• RUC extends commitment

RUC Guaranteed Amount will not include Startup Costs
Startup Cost Eligibility

• One Start per contiguous block of committed hours
• RUC initially commits
• QSE extends commitment

RUC Guaranteed Amount will include Startup Costs

QSE Clawback Intervals
Must divide Real-Time Revenue into two types

- Revenue less Incremental Costs For RUC Hours
- Revenue less costs for QSE Clawback Intervals

Costs Incurred:
- Minimum-Energy Costs
- Startup Costs
Real-Time Revenue because of RUC

Revenue less Incremental Costs for RUC Hours

- Incremental Costs taken from Energy Offer Curve
- Subject to Make-Whole Cap

Average Incremental Energy Cost = Area / (MW Output above LSL)
Revenue less costs for QSE Clawback Intervals

- Incremental Costs taken from Energy Offer Curve
- Subject to Make-Whole Cap

Average Incremental Energy Cost = Area / (MW Output above LSL)
### Scenario 3: Revenue Summary

Generation Resource BIGGEN1 starts in Hour 6 and shuts down in Hour 11

<table>
<thead>
<tr>
<th></th>
<th>Revenue less Incremental Costs for RUC Hours</th>
<th>Revenue less Costs for QSE Clawback Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 6</td>
<td></td>
<td>$0</td>
</tr>
<tr>
<td>Hour 7</td>
<td>$1000</td>
<td></td>
</tr>
<tr>
<td>Hour 8</td>
<td>$1900</td>
<td></td>
</tr>
<tr>
<td>Hour 9</td>
<td>$2000</td>
<td></td>
</tr>
<tr>
<td>Hour 10</td>
<td>$1000</td>
<td></td>
</tr>
<tr>
<td>Hour 11</td>
<td></td>
<td>$0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$5900</td>
<td>$0</td>
</tr>
</tbody>
</table>
Scenario 3: RUC Make-Whole Payment Summary

What if revenues are less than costs?

<table>
<thead>
<tr>
<th>Make-Whole Payment</th>
<th>Costs Incurred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue less costs for QSE Clawback Intervals</td>
<td>Min-Energy Costs * LSL For each hour</td>
</tr>
<tr>
<td>Revenue less incremental costs For RUC Hours</td>
<td>Startup Costs</td>
</tr>
</tbody>
</table>

Revenues Received | Costs Incurred
What if revenues are less than costs?

**Scenario 3: RUC Make-Whole Payment Summary**

- **RUC Guaranteed Amount = $9000**
  - **Make-Whole Payment**
    - $3100
    - $775 per hour
  - **Revenues Received**
    - $5900
  - **Costs Incurred**
    - $30 / MWh * 50 MW
    - * 4 hours = $6000
  - **$3000**

- **Summary**
  - $0
  - $3000
Scenario 3: RUC-Related Settlement Summary

Generation Resource BIGGEN1 is Committed by RUC for 4 hours

<table>
<thead>
<tr>
<th>Hour</th>
<th>Real-Time Energy Imbalance</th>
<th>Make-Whole Payment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 6</td>
<td>$500</td>
<td>N/A</td>
<td>$500</td>
</tr>
<tr>
<td>Hour 7</td>
<td>$1000</td>
<td>$775</td>
<td>$1775</td>
</tr>
<tr>
<td>Hour 8</td>
<td>$2800</td>
<td>$775</td>
<td>$3575</td>
</tr>
<tr>
<td>Hour 9</td>
<td>$3020</td>
<td>$775</td>
<td>$3795</td>
</tr>
<tr>
<td>Hour 10</td>
<td>$1000</td>
<td>$775</td>
<td>$1775</td>
</tr>
<tr>
<td>Hour 11</td>
<td>$500</td>
<td>N/A</td>
<td>$500</td>
</tr>
<tr>
<td>Total</td>
<td>$8820</td>
<td>$3100</td>
<td>$11,920</td>
</tr>
</tbody>
</table>
What if revenues are greater than costs?

- **Revenues Received**: Real-Time Revenue less Incremental Costs
- **Costs Incurred**: Minimum-Energy Costs, Startup Costs
- **RUC Guaranteed Amount**: Total of Minimum-Energy Costs and Startup Costs
What if revenues are greater than costs?

- **Subject to Clawback**
  - Real-Time Revenue less Incremental Costs

- **RUC Guaranteed Amount**
  - Minimum-Energy Costs
  - Startup Costs

**Revenues Received** vs. **Costs Incurred**
Clawback amount depends on circumstances

<table>
<thead>
<tr>
<th></th>
<th>Three-Part Supply Offer in DAM</th>
<th>No Three-Part Supply Offer in DAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clawback Percentage for RUC hours</td>
<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>Clawback Percentage for QSE Clawback Intervals</td>
<td>0%</td>
<td>50%</td>
</tr>
</tbody>
</table>
Don’t forget – the QSE may have Opted Out

Operational Conditions

- ONOPTOUT Resource Status
  - COP
  - Telemetry
- Must have run resource if available
- May have provided ancillary services

Financial Impacts

- No RUC Make-Whole Payments or Clawback Charges apply
- QSE chose how to price the Energy Offer Curve
Real-Time Market Settlement Statements

- Payments due and Charges incurred
- Posted to MIS Certified Area
Single Daily Settlement Invoice

Settlement Timelines

- Invoice Day
  - ERCOT Issues Invoice
    - DAM
    - RTM Initial
    - RTM Final
    - RTM True-up

- Invoice Day + 2
  - Payment Due to ERCOT
  - 1700

- Invoice Day + 3
  - Payment Due to Market Participant
  - 1700
You’ve learned about ...

- Real-Time Dispatch and Formation of Dispatch Limits
- The Mind of SCED (Security Constrained Economic Dispatch)
- Load Frequency Control and Primary Frequency Response
- Provision and Deployment of Ancillary Services
- Real-Time Settlements
This completes Resource 301!
You should now be able to …

• Summarize how ERCOT utilizes Resources to meet reliability goals

• Delineate the responsibilities of Resource Entities and QSEs in managing Resources

• Explain how Resource constraints are formed and predict how they impact market solutions

• Compare and contrast how Resources are utilized in Day-Ahead and Real-Time Operations

• Illustrate financial outcomes of the markets and evaluate strategies for offering resources.
ERCOT Protocols
http://www.ercot.com/mktrules/nprotocols/

ERCOT Training
http://www.ercot.com/services/training/

ERCOT Account Management Services
ErcotAccountManagers@ercot.com

ERCOT Credit
ERCOTCredit@ercot.com

ERCOT Market Education Contact
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