Module 5

Resources in Real-Time Operations
Topics in this module ...

• Real-Time Dispatch Overview

• 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
SCED requires multiple inputs
Security Analysis provides Transmission Constraints

Real-Time Dispatch

Security-Constrained Economic Dispatch

Constraints & Shift Factors

Network Operations Model

Contingencies

Telemetry

Offers

Pricing

Dispatch Instructions
Resource Limit Calculator determines Dispatch Limits

Energy Dispatch Process

Real-Time Dispatch

Offers

Resource Limit Calculator
Constraints & Shift Factors

Security-Constrained Economic Dispatch

Network Operations Model

Telemetry

Contingencies

Pricing

Dispatch Instructions
Dispatch Limits (for Generation Resources)

High Sustained Limit

Telemetered by the QSE every few seconds

Low Sustained Limit
High Sustained Limit

Also telemetered by QSE
- AS Schedule (RRS & Non-Spin)
- AS Resource Responsibility (Reg)

Low Sustained Limit
High Ancillary Service Limit

HASL = Current HSL
  – (AS Schedule for RRS & NS)
  – (AS Responsibility for Reg-Up)

Low Ancillary Service Limit

LASL = Current LSL
  + (AS Responsibility for Reg-Down)
SCED Up Ramp Rate

\[
\text{SURAMP} = \text{Up Ramp Rate} - (\text{Reg-Up Responsibility} \times \text{REGP} / 5)
\]

SCED Down Ramp Rate

\[
\text{SDRAMP} = \text{Down Ramp Rate} - (\text{Reg-Down Responsibility} \times \text{REGP} / 5)
\]

REGP is currently set at \(5/7 = 0.714\)
Dispatch Limits (for Generation Resources)

High Dispatch Limit

HDL = Operating Point + (SURAMP * 5)

HDL ≤ HASL

Low Dispatch Limit

LDL = Operating Point – (SDRAMP * 5)

LDL ≥ LASL

Reg-Up, RRS & Non-Spin

SCED Up RAMP

Operating Point

Base Point Region

SCED Dn RAMP

Reg-Down

5 minutes

HASL

HSL

HDL

LDL

LASL

LSL
Example 1

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

- HDL = 150MW + (3MW/min * 5 min) = 165MW
- LDL = 150MW – (4MW/min * 5 min) = 130MW

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

**What are HDL and LDL?**
Example 2

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

**Reg-Up**

**HASL**

**HDL**

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

Reg-Up Resource Responsibility = 14MW

**What is HDL?**

\[
\text{HDL} = 150\text{MW} + \left( \frac{1\text{MW/min}}{5\text{min}} \times 5\text{min} \right)
\]

\[
\text{HDL} = 150\text{MW} + 1\text{MW}
\]

\[
\text{HDL} = 155\text{MW}
\]
Dispatch Limits (for Load Resources)

High Dispatch Limit

HDL = Operating Point + (SDRAMP * 5)

HDL \leq \text{HASL}

Low Dispatch Limit

LDL = Operating Point – (SURAMP * 5)

LDL \geq \text{LASL}

HSL

HASL

HDL

LDL

LASL

LSL

5 minutes
SCED must also have a Power Balance Constraint

Energy Dispatch Process

Real-Time Dispatch

Security-Constrained Economic Dispatch

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

Offers

Pricing

Dispatch Instructions
Offers allow SCED to achieve economic dispatch
Energy Offer Curves for Generation Resources:

Avenues to Real-Time:

- Awarded offer in DAM
- Committed through RUC
- Committed by QSE

Resource with no Offer Curve:

- Is a price taker at current output
- Is last to be moved
Output Schedules for Generation Resources

- For Resources constrained to run at specific Output levels
- Specifies “required” output level for each five-minute interval
RTM Energy Bid for Load Resources:

Loads in SCED:

- Controllable Load Resources may qualify
- Bid represents price tolerance
- Load curtailed at the right price

May be an Aggregate Load Resource
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
SCED Objective:

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

- $SP_{demand}$ 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 $SP_{demand}$
- Each Transmission constraint has a max $SP_c$
## Power Balance Penalty for Under-Generation

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

### Diagram

A graph showing the power balance penalty for under-generation. The x-axis represents MW violation, and the y-axis represents $/MWh. The graph indicates a stepwise increase in penalties as the MW violation increases.
Power Balance Penalty for Over-Generation

<table>
<thead>
<tr>
<th>MW Violation</th>
<th>$/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ≤ MW</td>
<td>-250</td>
</tr>
</tbody>
</table>

Any Power Balance violation by SCED will be covered by Regulation
Penalty for Violating Transmission Constraint

<table>
<thead>
<tr>
<th>Shadow Price Caps</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Violation</strong></td>
</tr>
<tr>
<td>Base Case / Voltage</td>
</tr>
<tr>
<td>N-1 Constraint</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Cost for violating constraint depends on

- Shadow Price Cap
- MW violation amount
Determining Locational Marginal Prices for Energy

\[
LMP_{bus} = SP_{demand} - \sum_c SF_{bus,c} \cdot SP_c
\]

- \( LMP_{bus} \): Locational Marginal Price of the bus
- \( SP_{demand} \): Shadow Price of the demand
- \( SF_{bus,c} \): Shift Factor of the bus on Transmission Constraint “c”
- \( SP_c \): Shadow Price of the constraint "c"

Also known as System Lambda (\( \lambda \))

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

Ramp Rates:
- Normal Up = 2MW/min
- Normal Down = 3MW/min

SCED runs at 1100 and dispatches the Resource to 80MW @ $40.

Five minutes later a constraint causes SCED to set the LMP to –$1000, but the Resource still receives a Base Point of 80MW.

What’s 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 of Resources,
• Without cost optimization

... so what’s the real difference?
Governors:

• What do they do?

• Why are they needed?
Governor in Service Requirements

When an All-Inclusive Resource is On-Line

• Governor must remain in service
• Must be allowed to respond to changes in system frequency

... after a point
Control of System Frequency

![Graph showing system frequency over time. The graph plots system frequency (Hz) against time (seconds). The x-axis represents time in seconds, ranging from 0 to 300, and the y-axis represents system frequency in Hz, ranging from 59.950 to 60.050. There are fluctuations in frequency throughout the time period.]
Control of System Frequency

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

System Frequency (Hz)

Governor Deadband

Time (seconds)

0           +50           +100          +150           +200          +250          +300

60.017

60.000

59.983
Control of System Frequency

Outside Deadbands:
- Load Frequency Control
- Governor response from most Resources
## Governor Droop and Deadband Settings

<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>

<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.
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?
Control of System Frequency

± 0.05Hz Thresholds:
- Load Frequency Control
- Governor response
- Suspend ramping that harms frequency
Ramping Suspension

System Frequency (Hz)

Resource Output (MW)

Time (seconds)

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. Resource Limits by Ancillary Service Product
2. Ancillary Service Deployment Methodologies
Who carries what?

On-line Generation Resources

Controllable Load Resources

Wholesale Storage Loads

On-line Generation Resources

Controllable Load Resources

Load Resources on Under-Frequency Relay

Off-line Generation Resources

On-line Generation Resources

Controllable Load Resources
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 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>$\text{LSL} + \text{Responsive} + \text{Regulation} + \text{Non-Spin} \leq \text{HSL}$</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>• 50% of ERCOT Responsive Reserve requirement</td>
</tr>
<tr>
<td></td>
<td>• 50% of QSE’s Self arranged Responsive Reserve</td>
</tr>
<tr>
<td></td>
<td>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 choses 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

Legend

| \(F_S\) | Scheduled Frequency |
| \(F_S\) | Actual Frequency |
| \(\beta\) | System Frequency Bias (Currently 739 MW/0.1Hz) |
Area Control Error (ACE)

Regulate Down when ACE > 0

Regulate Up when ACE < 0
Regulation Service ICCP Communications

ERCOT to QSEs every 4 seconds:
- Regulation Up MW
- Regulation Down MW

QSEs to ERCOT every 2 seconds:
- AS Resource Responsibility
- Participation Factors
- Raise/Lower Block Status
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

- ICCP Control Signal
  - Generation Resources
  - Controllable Load Resource
- XML Message to Load Resource
- Under-Frequency Relay trip of Load Resource
Responsive Reserve Service

Used under normal operations to recover from significant frequency deviations

Frequency Triggers

- 59.91 Hz – Automatic LFC deployment for Resources other than Load Resources on Under Frequency Relay
- 59.7 Hz – Load Resources on Under Frequency Relay trip after a 20 cycle delay
Responsive Reserve ICCP Communications

ERCOT to QSEs every 4 seconds:
• Responsive Reserve MW

QSEs to ERCOT every 2 seconds:
• AS Resource Responsibility
• AS Schedule by Resource

For Responsive Reserve:
AS Schedule = AS Resource Responsibility – AS Deployment
Responsive Reserve ICCP Communications

QSE adjusts each Resource’s AS Schedule within 1 minute to reflect the Responsive Reserve deployment.

SCED is triggered and energy from Resource is dispatched by SCED at Emergency Ramp Rate.
Name that Frequency!

Summary of Frequency Triggers

Class Activity

- **Primary Frequency Response**
  - Suspend Ramping through UDBP
  - FRRS Down Deploys Automatically
  - FRRS Up and RRS Deploy Automatically

- **Load Resources on UFR trip**
  - ERCOT may begin load shedding
  - ERCOT shall begin load shedding
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 must set Non-Spin Schedule to zero within 20 minutes
• Resource must be 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
On-Line Generation Resource (with Power Augmentation)

- Non-Spin provided through Power Augmentation not subject to Standing Deployment
- Non-Spin Schedule = MW provided by Power Augmentation
- Deployed by Operator Dispatch Instruction
- QSE must set Non-Spin Schedule to zero within 20 minutes
Controllable Load Resource

• Deployed by Operator Dispatch Instruction

• QSE must set Non-Spin Schedule to zero within 20 minutes

• Dispatched by SCED

Real power consumption must be at least here
Real-Time Settlements
Topics in this Section Include

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

\[
(-1) \left( \left( \text{DAM Energy Purchases} + \text{Trade Energy Purchases} \right) - \left( \text{DAM Energy Sales} + \text{Trade Energy Sales} \right) \right) \ast \text{RTSPP}
\]

\[
+ (-1) \left( \text{Metered Generation} \right) \ast \text{RTRMPR}
\]
At a Resource Node,

RTSPP is used to settle financial transactions

$$\text{RTSPP} = \text{RTRSVPOR} + \text{RTRDP} + \text{Time-Weighted Average LMPs}$$

<table>
<thead>
<tr>
<th>RTSPP</th>
<th><strong>Real-Time Settlement Point 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>
At a Resource Node,

RTRMPR is used to settle physical energy production

\[ \text{RTRMPR} = \text{RTRSVPOR} + \text{RTRDP} + \text{(Base-Point \* Time)} \]

\(\text{RTRMPR} = \text{LMPs} \)

<table>
<thead>
<tr>
<th>RTRMPR</th>
<th>Real-Time Resource Meter 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>
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
Real-Time Resource Settlements

Scenario 1

Real-Time Energy Imbalance for Interval 0015:

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

Which simplifies and re-arranges to . . .

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

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

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

Scenario 1

Real-Time Energy Imbalance for Interval 0045:

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

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

Scenario 1

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>1</td>
<td>$158</td>
</tr>
<tr>
<td>2</td>
<td>$200</td>
</tr>
<tr>
<td>3</td>
<td>$225</td>
</tr>
<tr>
<td>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>
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>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td><strong>129</strong></td>
</tr>
</tbody>
</table>

Energy Offer Curve
Real-Time Resource Settlements

Scenario 2

Real-Time Energy Imbalance for Interval 1315:

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

\[
(-1) \times \left( 30 \text{ MWh} \times $27/\text{MWh} - 25 \text{ MWh} \times $27/\text{MWh} \right) = -$135
\]
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>Real-Time Revenue</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 14</td>
<td>$300</td>
</tr>
<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>$406</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$ 4877</strong></td>
</tr>
</tbody>
</table>
Topics in this Section Include

1. Real-Time Energy Imbalance
2. Settlement of RUC-Committed Resources
Generation Resource BIGGEN1 is committed by RUC

- Startup Offer: $3000
- Minimum Energy Offer: $30/MWh
- LSL = 50 MW
Generation Resource BIGGEN1 is committed by RUC

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

<table>
<thead>
<tr>
<th>Hour 15</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><strong>Total</strong></td>
<td><strong>50</strong></td>
<td><strong>50</strong></td>
<td><strong>50</strong></td>
</tr>
</tbody>
</table>

Energy Offer Curve

- $1500 / MWh
- 50 MW (LSL)
Real-Time Resource Settlements

Scenario 1

Real-Time Energy Imbalance for Interval 0615:

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

\[ (-1) \times (12.5 \text{ MWh} \times $20/\text{MWh} - 0 \times $20/\text{MWh}) = -$250 \]

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

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

- **Make-Whole Payment**
- **Real-Time Revenue less Incremental Costs**
- **Minimum Energy Costs**
- **Startup Costs**

Revenues Received vs. Costs Incurred
Make-Whole Payments and Caps

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

Costs to be made whole:

<table>
<thead>
<tr>
<th>Startup Offer</th>
<th>Minimum Energy Offer</th>
</tr>
</thead>
<tbody>
<tr>
<td>$/Start</td>
<td>$/MWh</td>
</tr>
</tbody>
</table>
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
Must divide Real-Time Revenue into two types

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

- Minimum Energy Costs
- Startup Costs
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

\[
\text{Average Incremental Energy Cost} = \frac{\text{Area}}{(\text{MW Output above LSL})}
\]
Scenario 1

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><strong>Hour 6</strong></td>
<td></td>
<td>$0</td>
</tr>
<tr>
<td><strong>Hour 7</strong></td>
<td>$1000</td>
<td></td>
</tr>
<tr>
<td><strong>Hour 8</strong></td>
<td>$1900</td>
<td></td>
</tr>
<tr>
<td><strong>Hour 9</strong></td>
<td>$2000</td>
<td></td>
</tr>
<tr>
<td><strong>Hour 10</strong></td>
<td>$1000</td>
<td></td>
</tr>
<tr>
<td><strong>Hour 11</strong></td>
<td></td>
<td>$0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$5900</td>
<td>$0</td>
</tr>
</tbody>
</table>
What if revenues are less than costs?

Scenario 1

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

- Costs Incurred
  - Min Energy Costs * LSL For each hour
  - Startup Costs

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

Scenario 1

RUC Guaranteed Amount = $9000

Make-Whole Payment = $3100 = $775 per hour

$5900

$0

Revenues Received

Costs Incurred

$30 / MWh * 50 MW * 4 hours = $6000

$3000

$6000
Scenario 1

Generation Resource BIGGEN1 is Committed by RUC for 4 hours

<table>
<thead>
<tr>
<th></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**: RUC Guaranteed Amount
  - Minimum Energy Costs
  - Startup Costs
What if revenues are greater than costs?

- Revenues Received
  - Subject to Clawback
    - Real-Time Revenue less Incremental Costs

- Costs Incurred
  - RUC Guaranteed Amount
    - Minimum Energy Costs
    - Startup Costs
Clawback amount depends on circumstances

<table>
<thead>
<tr>
<th>Clawback Percentage for</th>
<th>Three-Part Supply Offer in DAM</th>
<th>No Three-Part Supply Offer in DAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUC hours</td>
<td>50%</td>
<td>100%</td>
</tr>
<tr>
<td>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

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

- Real-Time Dispatch
- 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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