Topics in this module ...

- Day-Ahead Market (DAM) Overview
- Formation of Resource Constraints in DAM
- The Mind of DAM
- QSE Responsibilities post-DAM
- DAM Settlements
Overview
The Day-Ahead Market

- Offers
- Bids
- Current Operating Plans
- Network Operations Model

Day-Ahead Market

- Pricing
- Awards
The Day-Ahead Market

Resource Specific Offers:
- Three-Part Supply Offer
- Ancillary Service (AS) Offer
The Day-Ahead Market

- Offers
- Bids
- Current Operating Plans
- Network Operations Model

Day-Ahead Market

Ensures that DAM solution does not violate transmission constraints
The Day-Ahead Market

Offers

Bids

Current Operating Plans

Network Operations Model

Day-Ahead Market

Pricing

Used to form Resource Constraints:

- Low Sustained Limit
- High Sustained Limit
- Resource Status at beginning of day
Formation of Resource Constraints in DAM
Topics in this Section Include

1. Resource Limits
2. Linked Offers
3. Temporal Constraints
4. Combined Cycle Transitions
5. Split Generation Resources
The following limits are enforced by Day-Ahead Market:

<table>
<thead>
<tr>
<th>Generation Resources</th>
<th>Responsive Reserve</th>
<th>Award ≤ 20% of HSL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy and AS Capacity</td>
<td></td>
<td>Award ≤ 10 * Emergency Ramp Rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load Resources</td>
<td>Responsive Reserve</td>
<td>Award ≤ HSL - LSL</td>
</tr>
</tbody>
</table>

HSL and LSL are taken from Current Operating Plan.
Ramp Rate limitations are the QSEs responsibility!

- Aside from Responsive Reserve volume, DAM does not consider Ramp Rates

  - DAM may award more Ancillary Services than the Resource can physically provide in Real-Time

  - DAM may award more Energy than Resource can physically provide for the first few SCED cycles in an hour.
A QSE offers a Generation Resource for Ancillary Services in DAM:

- 50MW Regulation-Up (Reg-Up)
- 100MW Responsive Reserve (RRS)

**DAM can award both offers**

Real-Time requirements:

- Must be capable of providing all Reg-Up in 5 minutes (10MW/min ramp)
- If RRS deployed, must be capable of providing an additional 100 MW in 10 minutes (10MW/min ramp)
- Total Ramp Rate required = 20MW/min

<table>
<thead>
<tr>
<th>Resource Limits</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HSL</td>
<td>500MW</td>
</tr>
<tr>
<td>LSL</td>
<td>100MW</td>
</tr>
<tr>
<td>Normal Ramp Rate</td>
<td>10MW/min</td>
</tr>
<tr>
<td>Emergency Ramp Rate</td>
<td>10MW/min</td>
</tr>
</tbody>
</table>

Resource cannot provide both awards simultaneously
A QSE manages Ramp Rates with offers:

- 50MW Regulation-Up (Reg-Up)
- 50MW Responsive Reserve (RRS)

**Scenario 2: Ramp Rate Considerations**

**DAM awards both offers**

In Real-time:

- Ramp Rate = 10MW/min
- Responsive is deployed at t = 0
- Reg-Up consumes Ramp Rate during first SCED interval
- SCED utilizes RRS capacity during second SCED interval
Generalizing this approach . . .

The QSE will be able to meet their ramping requirements by adhering to the following guidelines.

<table>
<thead>
<tr>
<th>Offer</th>
<th>Less than or equal to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation Up</td>
<td>NRR * 5</td>
</tr>
<tr>
<td>Responsive Reserve Service</td>
<td>Min(0.20 * HSL, ERR * 10 – REGUP offer)</td>
</tr>
<tr>
<td>Non-Spin Reserve Service</td>
<td>Min(NRR * 20 + ERR * 10 – REGUP – RRS, NRR * 30)</td>
</tr>
<tr>
<td>Regulation Down</td>
<td>NRR * 5</td>
</tr>
</tbody>
</table>

Where NRR = Normal Ramp Rate
ERR = Emergency Ramp Rate
Scenario 3: Ramp Rate Considerations

A QSE offers a Generation Resource in DAM:
- 300MW Non-Spin Reserve (NSRS)
- 300MW Energy

**DAM awards as follows:**

<table>
<thead>
<tr>
<th>Time (Hour)</th>
<th>Non-Spin</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td>9-12</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>14-24</td>
<td>300</td>
<td>0</td>
</tr>
</tbody>
</table>

**Resource Limits**
- **HSL:** 300MW
- **LSL:** 50MW
- **Normal Ramp Rate:** 10MW/min

In Real-time:
- Ramp rate constrained during first half of Hour 13
- QSE will buy back part of DAM award
Topics in this Section Include

1. Resource Limits
2. Linked Offers
3. Temporal Constraints
4. Combined Cycle Transitions
5. Split Generation Resources
A QSE may offer a Generation Resource for:

- Energy
  - Three-Part Supply Offer
  - Stand alone Energy Offer Curve
- Any or all Ancillary Services
- Ancillary Services and Energy Simultaneously

Energy Offer Curve must be flagged as inclusive or exclusive of Ancillary Service Offers
Inclusive vs. Exclusive Offers

**Inclusive Offers**

- Available Capacity
- Ancillary Services
- and
- Energy
Inclusive vs. Exclusive Offers

Exclusive Offers

- Available Capacity
- Ancillary Services
- or -
- Energy
Example 1: Linked Offers (1/3)

A Set of Inclusive Offers

Available Capacity

Responsive
Reg-Up
Reg-Down

Offline Non-Spin

Inclusive Three Part Supply Offer
Example 1

Possible Awards – Case A

Available Capacity

Reg-Down
Responsive
Reg-Up

Energy
Example 1: Linked Offers (3/3)

Possible Awards – Case B

- Available Capacity
- Responsive
- Energy
Example 2: Linked Offers (1/3)

A set of Exclusive Offers

Available Capacity

Reg-Down  Responsive  Reg-Up

Offline Non-Spin

Exclusive Three Part Supply Offer
Example 2: Linked Offers (2/3)

Possible Awards – Case A

Available Capacity

Offline Non-Spin
Example 2: Linked Offers (3/3)

Possible Awards – Case B

← Available Capacity →

Reg-Down  Responsive  Reg-Up

Energy

0 MW  LSL  HSL
QSE has committed the Resource to cover trades. Would like to offer remaining capacity to DAM.

Linked Offers with Resource Already Planned to Run

Setup

0 MW | 150 MW | HSL= 300 MW

← Obligated by Trades → ← Available Capacity →

Ancillary Service Offers?

Energy Offer?
Example 3: Linked Offers (1/2)

Inclusive Three Part Supply Offer
- Startup Offer = $0
- Minimum-Energy = $0

Example 3

0 MW 150 MW HSL= 300 MW

Obligated by Trades
- LSL= 100 MW

Available Capacity
- Reg-Up 75 MW

Energy Offer 75 MW
Possible Awards

Example 3: Linked Offers (2/2)

0 MW 150 MW HSL = 300 MW

← Obligated by Trades →

LSL = 100 MW

← Available Capacity →

Reg-Up

75 MW

Energy

75 MW

Available Capacity

Obligated by Trades
Inclusive Three Part Supply Offer

- **Startup Offer = $0**
- **Minimum-Energy = $0**

**Example 4:**

- **Energy Offer**
  - 75 MW

- **Obligated by Trades**
  - LSL = 100 MW

- **Available Capacity**
  - HSL = 300 MW
  - Reg-Up = 75 MW
Example 4: Linked Offers (2/2)

Possible Awards

- Obligated by Trades
  - LSL = 100 MW
- Available Capacity
  - Reg-Up = 75 MW
- Energy
  - HSL = 300 MW
  - Available capacity = 150 MW
  - Possible awards = 75 MW
Example 5: Linked Offers (1/2)

DAM Self-Commitment
- Startup Offer is NULL
- Minimum-Energy Offer is NULL
- No Offline Non-Spin Offer

Example 5

Energy Offer

0 MW

Obligated by Trades

150 MW

Available Capacity

HSL = 300 MW

Reg-Up

75 MW

LSL constraint ignored

75 MW

LSL = 100 MW
Example 5: Linked Offers (2/2)

**Possible Award**

*Only HSL constraint enforced*

- **Obligated by Trades**
  - 0 MW
  - 150 MW
- **Available Capacity**
  - HSL = 300 MW
- **Reg-Up**
  - 75 MW
- **Energy**
  - 75 MW
- **Possible Award**
  - HSL0 MW
  - 150 MW
  - 75 MW
Resource Constraints in DAM – Temporal Constraints

Topics in this Section Include

1. Resource Limits
2. Linked Offers
3. Temporal Constraints
4. Combined Cycle Transitions
5. Split Generation Resources
DAM enforces the following Temporal Constraints for Three-Part Supply Offers

- Min On-Line Time
- Min Off-Line Time
- Maximum Daily Starts
Topics in this Section Include

1. Resource Limits
2. Linked Offers
3. Temporal Constraints
4. Combined Cycle Transitions
5. Split Generation Resources
Awarding Combined Cycle Plants in DAM

- QSE may offer all available configurations
- DAM may award
  - Only one configuration per hour
  - Transitions in accordance with registered transition matrix
Topics in this Section Include

1. Resource Limits
2. Linked Offers
3. Temporal Constraints
4. Combined Cycle Transitions
5. Split Generation Resources
Resource MPD is set up as two Split Generation Resources (SGR)

Each QSE provides a Three-Part Supply Offer

- Energy Offer Curves are awarded independently
- Startup and Minimum-Energy Offers must be awarded together

*What happens if each QSE provides only an Energy Offer Curve?*
• Optimize clearing of Bids and Offers
• Subject to various constraints
  • Security constraints
    • Power Balance Constraint
    • Transmission Constraints
  • Resource constraints
  • Linked Offer constraints
  • Block Bid and Offer constraints
  • Ancillary Service requirements

DAM Objective – Optimize with Constraints
Maximize:

Bid-Based Revenues

– Offer-Based Costs

– Penalty Costs
Bid-Based Revenues include:

- Cleared Energy Bids
- Cleared PTP Obligation Bids
Offer-Based Costs include:

- Cleared Energy Offers
- Cleared Ancillary Service Offers
- Startup Costs
- Minimum-Energy Costs
- Combined Cycle Transition Costs

Because of **Co-optimization**, these costs could be from the same physical Resources.
Penalty Costs are assigned costs for violating the following constraints:

- Power Balance Constraint
- Transmission Constraints
- Ancillary Service requirement per AS Type

Penalty costs drive the DAM to respect these constraints
To Maximize the Objective Value

Why is the DAM Objective programmed this way?
But offers from Resources are lumpy!

The cumulative offer curve depends on how DAM commits Resources.
Mixed-Integer Programming Gap (or MIP Gap)
DAM Optimization calculates Shadow Prices

- $SP_{demand}$ for the Power Balance Constraint
- $SP_c$ for each Transmission Constraint
- $SP_{(AS)}$ for each Ancillary Service Requirement
  - Regulation Up
  - Regulation Down
  - Responsive Reserve
  - Non-Spin Reserve Service

The Shadow Price for a constraint is the rate of change in Objective Value with respect to the constraint.
Determining Locational Marginal Prices for Energy

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

- Also known as System Lambda (\( \lambda \))
- Shift Factor of the bus on Transmission Constraint “c”
Introducing a simple model ...

Examples

MW = Transmission Capacity

= Settlement Point
We must define the Reference Bus

The Shadow Price for the Power Balance Constraint is determined at the reference bus.

Examples

= Settlement Point
MW = Transmission Capacity
### Example 1: DAM Clearing

#### Energy Transactions with Transmission Limits and PTP Obligations

<table>
<thead>
<tr>
<th>QSE</th>
<th>Product</th>
<th>Bid or Offer</th>
<th>Location</th>
<th>MW</th>
<th>Price</th>
<th>Award</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSE 1</td>
<td>Energy</td>
<td>Offer</td>
<td>A</td>
<td>100</td>
<td>$20</td>
<td></td>
</tr>
<tr>
<td>QSE 2</td>
<td>Energy</td>
<td>Offer</td>
<td>C</td>
<td>60</td>
<td>$30</td>
<td></td>
</tr>
<tr>
<td>QSE 3</td>
<td>Energy</td>
<td>Bid</td>
<td>D</td>
<td>90</td>
<td>$40</td>
<td></td>
</tr>
<tr>
<td>QSE 4</td>
<td>PTP Obl</td>
<td>Bid</td>
<td>A to B</td>
<td>30</td>
<td>$20</td>
<td></td>
</tr>
</tbody>
</table>

#### Bid-based Revenue – Offer-based Cost (Objective Value)

\[
(30 \times 20) + (90 \times 40) - (70 \times 20) - (20 \times 30) = 2200
\]

\[
(10 \times 20) + (90 \times 40) - (90 \times 20) - (0 \times 30) = 2000
\]

#### Shadow Prices

- \( \text{SP}_{\text{demand}} \)
- \( \text{SP}_{\text{constraint AB}} \)
Example 1: Price Formation

Determining Locational Marginal Prices

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

Diagram:
- Reference Bus
- Points A, B, C, D
- LMP = ? at each point

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**Example 1: Summary**

**In summary . . .**

<table>
<thead>
<tr>
<th>Result</th>
<th>MW</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSE 1 sells Energy at A</td>
<td>70</td>
<td>$20</td>
</tr>
<tr>
<td>QSE 2 sells Energy at C</td>
<td>20</td>
<td>$30</td>
</tr>
<tr>
<td>QSE 3 buys Energy at D</td>
<td>90</td>
<td>$30</td>
</tr>
<tr>
<td>QSE 4 buys PTP Obligations from A to B</td>
<td>30</td>
<td>$10</td>
</tr>
</tbody>
</table>

(Sink – Source)
Example 2: DAM Clearing

Energy Transactions with Transmission Limits and PTP Obligations

<table>
<thead>
<tr>
<th>QSE</th>
<th>Product</th>
<th>Bid or Offer</th>
<th>Location</th>
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<th>Award</th>
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<td>D</td>
<td>90</td>
<td>$40</td>
<td></td>
</tr>
<tr>
<td>QSE 4</td>
<td>PTP Obl</td>
<td>Bid</td>
<td>A to B</td>
<td>30</td>
<td>$5</td>
<td></td>
</tr>
</tbody>
</table>

Bid-based Revenue – Offer-based Cost (Objective Value)

- SP\text{demand}
- SP\text{constraint AB}
Determining Locational Marginal Prices

Example 2: Price Formation

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

- \( LMP = ? \) at bus A
- \( LMP = ? \) at bus B
- \( LMP = ? \) at bus C
- \( LMP = ? \) at bus D

Reference Bus
Example 2: Summary

In summary . . .

<table>
<thead>
<tr>
<th>Result</th>
<th>MW</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSE 1 sells Energy at A</td>
<td>90</td>
<td>$20</td>
</tr>
<tr>
<td>QSE 2 sells Energy at C</td>
<td>0</td>
<td>$25</td>
</tr>
<tr>
<td>QSE 3 buys Energy at D</td>
<td>90</td>
<td>$25</td>
</tr>
<tr>
<td>QSE 4 buys PTP Obligations from A to B</td>
<td>10</td>
<td>$5</td>
</tr>
<tr>
<td>(Sink – Source)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Determining Market Clearing Prices for Ancillary Services

- $MCPC_{(Reg-Up)} = SP_{(Reg-Up)}$
- $MCPC_{(Reg-Down)} = SP_{(Reg-Down)}$
- $MCPC_{(Responsive)} = SP_{(Responsive)}$
- $MCPC_{(Non-Spin)} = SP_{(Non-Spin)}$
QSE Responsibilities
Post-DAM
Day-Ahead Market Energy Award?

- QSE may update COP to show resource as ON
- May not
Day-Ahead Market Ancillary Service Award?

- QSE must update COP by 1430
- Show Ancillary Service on appropriate Resources

QSE may also cover obligation with AS Trade by 1430
Day-Ahead Market Settlements
DAM determines optimal clearing of Bids and Offers

- Energy Offers & Bids
- Ancillary Service Offers & Self-Arranged Qtys
- PTP Obligation Bids

Day-Ahead Market

Awards:
- Energy Offers & Bids
- Ancillary Service Offers
- PTP Obligation Bids
Day-Ahead Market Resource Settlements

Hourly Settlement = Price * Quantity
- **Price:** Settlement Point Price (SPP)
- **Quantity:** Awarded MW
- **Location:** Resource Node of the Resource

Hourly Settlement = Price * Quantity
- **Price:** Market Clearing Price for Capacity (MCPC) for each AS Type
- **Quantity:** Awarded MW
- **Location:** ERCOT (System-Wide)
Scenario: Day-Ahead Market Resource Settlements

Generation Resource BIGGEN1 is offered in DAM

- Startup Offer: $3000
- Minimum-Energy Offer: $30/MWh, LSL = 50 MW
- Responsive Reserve Offer: 10MW @ $10/MW

Assume Startup and Minimum-Energy Offers are at costs
Scenario

Generation Resource BIGGEN1 is awarded both Energy and Responsive Reserve for 4 hours

- Energy Award: 80MW @ $20
- Responsive Reserve Award: 10MW @ $10

Total Revenue = $6800

<table>
<thead>
<tr>
<th></th>
<th>Energy Revenue</th>
<th>AS Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 1</td>
<td>$1600</td>
<td>$100</td>
</tr>
<tr>
<td>Hour 2</td>
<td>$1600</td>
<td>$100</td>
</tr>
<tr>
<td>Hour 3</td>
<td>$1600</td>
<td>$100</td>
</tr>
<tr>
<td>Hour 4</td>
<td>$1600</td>
<td>$100</td>
</tr>
<tr>
<td>Total</td>
<td>$6400</td>
<td>$400</td>
</tr>
</tbody>
</table>

Does that cover their costs?
What Happened?

Day-Ahead Market Price Formation

LMPs are determined from incremental costs

- **Startup Offer**: $/Start
- **Minimum-Energy Offer**: $/MWh
- **Energy Offer Curve**: $/MWh vs. MW

Fixed costs

Incremental costs

LMPs are determined from incremental costs
What if revenues are less than costs?

- Energy Revenue
- AS Revenue

- Average Incremental Energy Costs
- Minimum-Energy Costs
- Startup Costs

DAM Guaranteed Amount

Revenues Received

Costs Incurred
What if revenues are less than costs?

- **Resource must run to be eligible**

<table>
<thead>
<tr>
<th>Revenues Received</th>
<th>Costs Incurred</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Revenue + AS Revenue</strong></td>
<td><strong>Average Incremental Energy Costs</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Minimum-Energy Costs</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Startup Costs</strong></td>
</tr>
</tbody>
</table>
Costs to be made whole:

- Look to Three-Part Supply Offer for cost data
- All costs subject to generic caps by Resource technology
Verifiable Costs on file?

• Startup and Minimum-Energy costs capped at Verifiable Costs

• Energy Offer Curve still subject to generic Make-Whole Cap
Generation Resource BIGGEN1 is offered in DAM

- Startup Offer: $3000
- Minimum-Energy Offer: $30/MWh, LSL = 50 MW
- Responsive Reserve Offer: 10MW @ $10/MW

Average Incremental Energy Cost

\[ \text{Average Incremental Energy Cost} = \frac{\text{Area}}{\text{(MW above LSL)}} = \$17.5 / \text{MWh} \]
What if revenues are less than costs?

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Make-Whole Payment</th>
<th>Costs Incurred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues Received</td>
<td>Energy Revenue + AS Revenue</td>
<td>AIEC * (Energy Sale – LSL) For each hour</td>
</tr>
<tr>
<td>Costs Incurred</td>
<td>Min-Energy Costs * LSL For each hour</td>
<td>Startup Costs</td>
</tr>
</tbody>
</table>
What if revenues are less than costs?

Make-Whole Payment = $4300
= $1075 per hour

DAM Guaranteed Amount = $11,100

$6800

$17.5 / MWh * (80 – 50 MW) * 4 hours = $2100

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

$3000
Scenario

Generation Resource BIGGEN1 is awarded both Energy and Responsive Reserve for 4 hours

- Energy Award: 80MW @ $20
- Responsive Reserve Award: 10MW @ $10

<table>
<thead>
<tr>
<th></th>
<th>Energy Revenue</th>
<th>AS Revenue</th>
<th>Make-Whole Revenue</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hour 1</td>
<td>$1600</td>
<td>$100</td>
<td>$1075</td>
<td>$2775</td>
</tr>
<tr>
<td>Hour 2</td>
<td>$1600</td>
<td>$100</td>
<td>$1075</td>
<td>$2775</td>
</tr>
<tr>
<td>Hour 3</td>
<td>$1600</td>
<td>$100</td>
<td>$1075</td>
<td>$2775</td>
</tr>
<tr>
<td>Hour 4</td>
<td>$1600</td>
<td>$100</td>
<td>$1075</td>
<td>$2775</td>
</tr>
<tr>
<td>Total</td>
<td>$6400</td>
<td>$400</td>
<td>$4300</td>
<td>$11,100</td>
</tr>
</tbody>
</table>
Day-Ahead Market Settlement Statements

- Payments due and Charges incurred
- Posted to MIS Certified Area
You’ve learned about ...

• The Day-Ahead Market (DAM)
• Formation of Resource Constraints in DAM
• The Mind of DAM
• QSE Responsibilities post-DAM
• DAM Settlements
Module Conclusion