ERCOT Market Education

Resource 301

Module 3: Resources in the Day-Ahead Market
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

Pricing

Awards
The Day-Ahead Market

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

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
## Resource Limits

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>Award ≤ 10 * Emergency Ramp Rate</td>
</tr>
<tr>
<td>Energy and AS Capacity</td>
<td></td>
<td>Total Award ≤ HSL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load Resources</th>
<th>Responsive Reserve</th>
<th>Award ≤ HSL - LSL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></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

**Resource cannot provide both awards simultaneously**

<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>
A QSE manages Ramp Rates with offers:

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

**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

HSL = 500 MW

- SCED Base Point
- Reg-Up
- RRS
- 400 MW
- 450 MW

\( t = 0 \) 5 10
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</th>
<th>Non-Spin</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Resource Limits**

<table>
<thead>
<tr>
<th>Resource</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSL</td>
<td>300MW</td>
</tr>
<tr>
<td>LSL</td>
<td>50MW</td>
</tr>
<tr>
<td>Normal Ramp Rate</td>
<td>10MW/min</td>
</tr>
</tbody>
</table>

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
Linked Offers – Exclusive

Inclusive vs. Exclusive Offers

Exclusive Offers

Available Capacity

Ancillary Services

- or -

Energy
Example 1: Linked Offers

A Set of Inclusive Offers

Example 1

0 MW  LSL  HSL

Available Capacity

Reg-Down  Responsive  Reg-Up

Offline Non-Spin

Inclusive Three Part Supply Offer
Example 1: Linked Offers

Possible Awards – Case A

- Available Capacity
- Reg-Down
- Responsive
- Reg-Up
- Energy
Example 1: Linked Offers

Possible Awards – Case B

Available Capacity

Responsive

Energy
Example 2: Linked Offers

A set of Exclusive Offers

- Available Capacity
- Reg-Down
- Responsive
- Reg-Up
- Offline Non-Spin
- Exclusive Three Part Supply Offer
Example 2: Linked Offers

Possible Awards – Case A

Available Capacity

Offline Non-Spin
Example 2: Linked Offers

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.

<table>
<thead>
<tr>
<th>Obligated by Trades</th>
<th>Available Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSL= 100 MW</td>
<td></td>
</tr>
</tbody>
</table>

Ancillary Service Offers?

Energy Offer?

0 MW | 150 MW | HSL= 300 MW

Linked Offers with Resource Already Planned to Run
Inclusive Three Part Supply Offer

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

Example 3: Linked Offers

- **Energy Offer**
  - 75 MW

- **Reg-Up**
  - 75 MW

- **Available Capacity**
  - 150 MW

- **Obligated by Trades**
  - 0 MW

HSL = 300 MW
Example 3: Linked Offers

What DAM actually sees
- Startup Offer = $0
- Minimum-Energy = $0
Example 3: Linked Offers

Possible Outcome

Available Capacity

DAM Energy Award
150 MW

150 MW Trade Obligation

Reg-Up
75 MW

HSL = 300 MW

0 MW
Example 4: Linked Offers

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

- Obligated by Trades
- Available Capacity

Energy Offer
- 75 MW

Reg-Up
- 75 MW

HSL = 300 MW

Example 4
Example 4: Linked Offers

What DAM actually sees

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

Example 4

Available Capacity

HSL = 300 MW

LSL = 100 MW

Reg-Up

Energy Offer

75 MW

75 MW
Example 4: Linked Offers

Possible Outcome

Available Capacity

DAM Energy Award

150 MW Trade Obligation

Reg-Up

HSL= 300 MW

0 MW

100 MW

75 MW

100 MW

Example 4
DAM Self-Commitment
- Startup Offer is *NULL*
- Minimum-Energy Offer is *NULL*
- No Offline Non-Spin Offer

Example 5: Linked Offers

Obligated by Trades
- LSL= 100 MW

Available Capacity
- HSL= 300 MW
- Reg-Up 75 MW

Energy Offer
- 75 MW
What DAM actually sees
• No Startup Offer
• No Minimum-Energy Offer

Example 5: Linked Offers

Available Capacity

Reg-Up

75 MW

Energy Offer

75 MW

LSL constraint ignored
Example 5: Linked Offers

Possible Outcome

Available Capacity

Reg-Up

DAM Energy

150 MW Trade Obligation

HSL = 300 MW

0 MW

75 MW
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 any available configurations
- DAM may award
  - One configuration per hour
  - Transitions per 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?
The Mind of DAM
DAM Objective – Optimize with Constraints

- 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

Day-Ahead Market
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.
Why is the DAM Objective programmed this way?

To Maximize the Objective Value
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

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

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

Examples

DAM Clearing and Price Formation – Simple Model

- Settlement Point
- MW = Transmission Capacity
We must define the Reference Bus

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

Examples

MW = Transmission Capacity

= Settlement Point
# Energy Transactions with Transmission Limits and PTP Obligations

## Example 1: DAM Clearing

<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)

- Bid-based Revenue = (90 × $40) – (90 × $20) = $2000
- Offer-based Cost = 10 × $20 + 90 × $40 = $4000

**Shadow Prices**

- SP<sub>demand</sub> = $30
- SP<sub>constraint AB</sub> = $10
Determining Locational Marginal Prices

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

Example 1: Price Formation

Reference Bus

A → B → C

LMP = ?

LMP = ?

LMP = ?

LMP = ?
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>
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<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>$5</td>
<td></td>
</tr>
</tbody>
</table>

#### Bid-based Revenue

- (10 × $5) + (90 × $40) - (70 × $20) - (20 × $30) = $1750

#### Offer-based Cost

- (10 × $5) + (90 × $40) - (90 × $20) - (0 × $30) = $1850

#### Shadow Prices

- $SP_{demand} = $25
- $SP_{constraint AB} = $5

---

[58]
Determining Locational Marginal prices

Example 2: Price Formation

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

![Diagram showing a network of buses A, B, C, and D with LMP = ? at each bus and a reference bus.](image)
Example 2: Summary

In summary . . .

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<th>Price</th>
</tr>
</thead>
<tbody>
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<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

- $\text{MCPC}_{\text{Reg-Up}} = \text{SP}_{\text{Reg-Up}}$
- $\text{MCPC}_{\text{Reg-Down}} = \text{SP}_{\text{Reg-Down}}$
- $\text{MCPC}_{\text{Responsive}} = \text{SP}_{\text{Responsive}}$
- $\text{MCPC}_{\text{Non-Spin}} = \text{SP}_{\text{Non-Spin}}$
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

Day-Ahead Market Awards

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

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

**Awarded Three-Part Supply Offers**

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

**Awarded Ancillary Service Offers**

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

- **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**
- **DAM Guaranteed Amount**
  - **Average Incremental Energy Costs**
  - **Minimum-Energy Costs**
  - **Startup Costs**

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

- Revenues Received: Energy Revenue + AS Revenue
- Costs Incurred: Average Incremental Energy Costs + Minimum-Energy Costs + Startup Costs

Resource must run to be eligible.
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
= Area / (MW above LSL)
= $17.5 / MWh
What if revenues are less than costs?

- Energy Revenue
- AS Revenue

Make-Whole Payment

AIEC * (Energy Sale – LSL)
For each hour

Min-Energy Costs * LSL
For each hour

Startup Costs

Scenario
What if revenues are less than costs?

DAM Guaranteed Amount = $11,100

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

$6800

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

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

$3000

Revenues Received
Costs Incurred
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