**RT Energy and AS Co-Optimization – Original and Modified Approach**

**Proposed Resource Specific AS Offer Submission Rule Modification:**

The proposed modifications to the Resource Specific AS Offer Submission rules are:

1. **Cascade of AS prices (MCPC) from higher quality AS to lower quality AS**

If a higher quality AS is offered then, the submitted prices for lower quality AS offer for the same offered MW quantity must be equal to or less than the offered higher quality AS.

For example, if 10 MW of RegUp is offered at 15 $/MW/h, then the submitted offer price for lower quality AS (RRS, Non-Spin, …) must be equal to or less than 15 $/MW/h

1. **Increased liquidity in the AS market**

If higher qualities AS offers are submitted with no prices for lower quality AS, then instead of the current practice of not using the offered AS MW for lower quality AS, ERCOT systems WILL consider these AS offer MW for lower quality AS at the same price as submitted for the higher quality AS.

For example, if 10 MW of RegUp offered at 15 $/MW/h but no prices submitted for lower quality AS (RRS, Non-Spin…), then, ERCOT systems will consider this offer for the qualified lower quality AS (RRS, Non-Spin,…) at 15 $/MW/h.

**Energy and AS co-optimization in the Day-Ahead and Real-Time Market**

In this section, modifications to the original approach in the concept paper are presented. The table below summarizes the key points of the original and modifications to the original for comparison.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Original** | | | **Modification** | | |
| AS Products | Day-Ahead | * RegUp, * RegDn, * RRS, * Non-Spin | Only awarded if offers submitted. i.e. willing seller | Day-Ahead | * RegUp, * RegDn, * RRS, * Spinning Operating Reserve (SOR), * Non-Spinning Operating Reserve (NSOR) | Only awarded if offers submitted. i.e. willing seller |
| Real-Time | * RegUp, * RegDn, * RRS, * Non-Spin | 1. For On-Line Non-Spin, if qualified, then automatically considered to be offered at zero $/MW 2. For other types of AS, will be awarded only if AS offer submitted. 3. Same MCPC for both On-Line and Off-Line Non-Spin | Real-Time | * RegUp, * RegDn, * RRS, * Spinning Operating Reserve (SOR), * Non-Spinning Operating Reserve (NSOR) | 1. For SOR, automatically considered to be offered at zero $/MW 2. For other types of AS, will be awarded only if AS offer submitted. 3. Separate prices (MCPC) for SOR and NSOR |
| AS Demand Curves | * The value of the maximum price on the ORDC needs to be coordinated with VOLL, SWOC. * Demand Curves for Regulation (Up/Down), and RRS are carved out of the ORDC for spinning (On-Line) reserves * Demand Curve for Non-Spin (includes On-Line and Off-Line) is carved out of the ORDC that represents both spinning and non-spinning (On-Line + Off-Line) reserves | | | * The value of the maximum price on each AS demand curve needs to be coordinated with VOLL,SWOC * Demand Curves for Regulation (Up/Down), and RRS do NOT have to be based on ORDC * Demand curve for SOR can be either the current ORDC for spinning (On-Line) reserves or based on EUE * Demand curve for NSOR can be either the current ORDC for spinning and non-spinning reserves (On-Line + Off-Line) or based on EUE | | |
| AS MCPC |  | | | * The SOR MCPC is the sum of the shadow prices of the constraints to procure SOR and NSOR | | |

**AS Demand Curves - Original**

MW

Minimum Contingency X=2000 MW

$/MW

$/MW

MW

RegUp Demand Curve

RRS Demand Curve

NSpin Demand Curve

ORDC – Spinning Reserves

ORDC – Combined Spinning & Non-Spinning Reserves

Minimum Contingency X=2000 MW

**AS Demand Curves – Modified (SOR,NSOR demand curves based on ORDC)**

$/MW

$/MW

RRS Demand Curve

RegUp Demand Curve

$/MW

$/MW

MW

MW

MW

MW

NSOR Demand Curve from ORDC Combined Spinning & Non-Spinning Reserves with Minimum Contingency (X) removed

SOR Demand Curve from ORDC Spinning Reserves with Minimum Contingency (X) removed

**Formulation of Equations**

The simplified formulation of the optimization problem (objective, constraints, pricing analysis) is presented below where energy and the various AS products are co-optimized in both Day-Ahead and Real-Time Markets.

Simplifications:

1. Transmission constraints in both Day-Ahead and Real-Time, PTPs, block offers and bids in Day-Ahead are not considered
2. Constraints on how much AS can be awarded to a single resource based on a % of HSL or ramp capability are not considered
3. are the submitted bids ($/MWh) , energy offers ($/MWh), AS offers ($/MW) respectively. For simplicity, these bids and offers are considered to be constant for the entire MW bid or offered.
4. In the Day-Ahead Market, Resources must submit offers to sell energy and AS (all the types) in order to be awarded.
5. The equations below are describing the modified approach. If the reader is interested in the equations for the original approach in the concept paper, then in the equations below:
   1. Consider SOR offers (spinning operating reserve) as Non-Spin (both On-Lin and Off-Line)
   2. Replace the demand curve for SOR with Non-Spin demand curve.
   3. Remove terms with NSOR (non-spinning operating reserve) – off-line non-spin is already included in (v) a. above.

**Day-Ahead Market Objective Function:**

**Real-Time Market Objective Function:**

**Subject to:**

Ignoring transmission constraints and focusing on power balance, AS procurement and the main Resource limit constraints, the set of constraints are given below:

**System wide constraints:**

1. Power Balance: (Shadow price = )

**Day-Ahead:**

**Real-Time:**

1. RegUp Procurement (including FRRS-Up): (Shadow price = )
2. FRRS-Up maximum procurement limit: (Shadow price = )
3. RegDn Procurement (including FRRS-Dn): (Shadow price = )
4. FRRS-Dn maximum procurement limit: (Shadow price = )
5. RRS Procurement: (Shadow price = )
6. RRS maximum procurement from “blocky” Load Resource: (Shadow price = )
7. SOR Procurement: (Shadow price = )
8. SNSOR Procurement: (Shadow price = )

**Individual Energy Bid constraints:**

1. Energy Bid MW constraint for every energy bid : (Shadow price = respectively)

**Individual Resource constraints:**

Each Resource will have its own set of constraints to ensure awards are within bounds of its own upper (HSL/MPC) and low (LSL/LPC) limits.

1. LSL Constraint for every modeled Generation Resource : (Shadow price = )
2. HSL Constraint for every modeled Generation Resource : (Shadow price = )

Online:

Offline:

1. AS Offer MW constraint for every modeled Generation Resource : (Shadow price = respectively)

Online:

Offline:

1. MPC & LPC Constraint for every modeled “Blocky” Load Resource : (Shadow price = )

Note that a “blocky” Load Resource is awarded only one AS product.

or

1. AS Offer MW constraint for every modeled “Blocky” Load Resource : (Shadow price = )

or

1. MPC & LPC Constraint for every modeled Controllable Load Resource : (Shadow price = )
2. AS Offer MW constraint for every Controllable Load Resource : (Shadow price = respectively)
3. HSL & LSL Constraint for every “Quick/Fast” Resource qualified for FRRS-Up and FFR1 and partly modeled as Generation Resource : (Shadow price = )
4. AS Offer MW constraint for every “Quick/Fast” Resource qualified for FRRS-Up and FFR1 and partly modeled as Generation Resource : (Shadow price = )
5. MPC & LPC Constraint for every “Quick/Fast” Resource qualified for FRRS-Up, FRRS-Dn and RRS and partly modeled as Controllable Load Resource : (Shadow price = )
6. AS Offer MW constraint for every “Quick/Fast” Resource qualified for FRRS-Up and FRRS-Dn and partly modeled as Controllable Load Resource : (Shadow price = respectively)

**Lagrangian Function:**

The objective and constraints are combined to form the Lagrange function:

At optimal solution (optimality condition)

i.e. the partial derivative of with respect to each award and the shadow prices will equate to zero at the optimal solution.

Taking the partial derivative of with respect to each award

and rearranging the terms by we get:

1. **Day Ahead:** For each energy bid , the following equation holds true

If the energy bid *i* is marginal to the power balance constraint, then and the energy bid *i* sets the shadow price for the power balance constraint (System Lambda )

**Real-Time:** If the Power Balance Penalty Curve is marginal to energy, the following equation holds true and the Power Balance Penalty Curve sets the shadow price for the power balance constraint (System Lambda ):

1. For each energy offer from modeled Generation Resource , the following equation holds true

If the energy offer *i* is marginal to the power balance constraint, then, and the energy offer *i* sets the shadow price for the power balance constraint (System Lambda )

1. For each RegUp offer from modeled Generation Resource , the following equation holds true

If the RegUp offer *i* is marginal to the RegUp Procurement constraint, then in most cases, and the RegUp Offer *i* sets the shadow price for the RegUp Procurement constraint ( this is the RegUp MCPC )

1. For each RegDn offer from modeled Generation Resource , the following equation holds true

If the RegDn offer *i* is marginal to the RegDn Procurement constraint, then, in most cases, and the RegDn Offer *i* sets the shadow price for the RegDn Procurement constraint ( this is the RegDn MCPC )

1. For each RRS offer from modeled Generation Resource , the following equation holds true

If the RRS offer *i* is marginal to the RRS Procurement constraint, then, and the RRS Offer *i* sets the shadow price for the RRS Procurement constraint (this is the RRS MCPC )

1. For each SOR offer from modeled Generation Resource , the following equation holds true

If the SOR offer *i* is marginal to the SOR Procurement constraint, then, .

Please note that the MCPC for SOR is the sum of the shadow price for the SOR and SNSOR () procurement constraints.

1. For each SNSOR offer from modeled offline Generation Resource , the following equation holds true

If the SNSOR offer *i* is marginal to the SNSOR Procurement constraint, then, .

Note that the MCPC for SNSOR is the shadow price for the SNSOR procurement constraint

1. For each RRS offer from modeled “blocky” Load Resource , the following equation holds true

If the RRS offer *i* is marginal to the RRS Procurement constraint, then, and the RRS Offer *i* sets the shadow price for the RRS Procurement constraint (this is the RRS MCPC )

Note that if the RRS offer MW is submitted as a **block**, then, this offer **cannot** set the MCPC

If the RRS maximum procurement constraint from “blocky” Load Resource is binding then . In this case the MCPC for RRS is still the shadow price of the RRS procurement constraint () and the RRS awards to “blocky” Load Resources will be paid this price

1. For each SOR offer from modeled “blocky” Load Resource , the following equation holds true

If the SOR offer *i* is marginal to the SOR Procurement constraint, then, and the SOR Offer *i* sets the shadow price for the SOR Procurement constraint (this is the SOR MCPC )

Note that if the SOR offer MW is submitted as a **block**, then, this offer **cannot** set the MCPC

1. For each RegUp offer from modeled Controllable Load Resource , the following equation holds true
2. For each RegDn offer from modeled Controllable Load Resource , the following equation holds true
3. For each RRS offer from modeled Controllable Load Resource , the following equation holds true
4. For each SOR offer from modeled Controllable Load Resource , the following equation holds true
5. For each FRRS-Up offer from “Quick/Fast” Resource partly modeled as Generation Resource , the following equation holds true

If the FRRS-Up offer *i* is marginal to the RegUp Procurement constraint, then, and the FRRS-Up Offer *i* sets the shadow price for the RegUp Procurement constraint (this is the RegUp MCPC )

If the FRRS-Up maximum procurement constraint from “Quick/Fast” Resource is binding then . In this case the MCPC for RegUp is still the shadow price of the RegUp procurement constraint () and the FRRS-Up awards to “Quick/Fast” Resources will be paid this price

1. For each FRRS-Up offer from “Quick/Fast” Resource partly modeled as Load Resource , the following equation holds true

If the FRRS-Up offer *i* is marginal to the RegUp Procurement constraint, then, and the FRRS-Up Offer *i* sets the shadow price for the RegUp Procurement constraint (this is the RegUp MCPC )

If the FRRS-Up maximum procurement constraint from “Quick/Fast” Resource is binding then . In this case the MCPC for RegUp is still the shadow price of the RegUp procurement constraint () and the FRRS-Up awards to “Quick/Fast” Resources will be paid this price

1. For each FRRS-Dn offer from “Quick/Fast” Resource partly modeled as Load Resource , the following equation holds true

If the FRRS-Dn offer *i* is marginal to the RegDn Procurement constraint, then, and the FRRS-Dn Offer *i* sets the shadow price for the RegDn Procurement constraint (this is the RegUp MCPC )

If the FRRS-Dn maximum procurement constraint from “Quick/Fast” Resource is binding then . In this case the MCPC for RegDn is still the shadow price of the RegDn procurement constraint () and the FRRS-Up awards to “Quick/Fast” Resources will be paid this price

Note: If there is scarcity in any of the AS (RegUp, RegDn, RRS, SOR and SNSOR), then the demand curves prices at the last cleared MW AS demand on the respective demand curves will set the Shadow Prices of the applicable procurement constraints.

**MCPC formula (from shadow prices)**

|  |  |  |
| --- | --- | --- |
| AS Product | MCPC | Comments |
| RegUp |  | Shadow price of the RegUp procurement (including FRRS-Up) constraint |
| FRRS-Up |  | FRRS-Up is valued the same as RegUp |
| RegDn |  | Shadow price of the RegDn procurement (including FRRS-Dn) constraint |
| FRRS-Dn |  | FRRS-Down is valued the same as RegDn |
| RRS |  | Shadow Price of the RRS procurement constraint |
| SOR |  | Sum of the Shadow Prices of the SOR and SNSOR procurement constraints |
| SNSOR |  | Shadow Price of the SNSOR procurement constraint |