**Real-Time Co-optimization Model**

**Objective Function (probabilistic model):**

Max ∑d [B(d-u) - C(g)] f(d) + DRUS(dRUS) + DRRS(dRRS) - CSOR(rSOR) - CRUS(rRUS) - CRRS(rRRS)

Or, simplifying by setting B(d) = VOLL\*d, making d and g the expected values of net load (GTBD) and generation, and x with mean 0 representing the uncertainty in net load:

Max ∑x [VOLL(d+x-u) - C(g+g')] f(x) + DRUS(dRUS) + DRRS(dRRS) - CSOR(rSOR) - CRUS(rRUS) - CRRS(rRRS)

**Subject to:**

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

**System wide constraints:**

1. Expected Power Balance: (Shadow price = ) g - d = 0
2. RegUp Procurement: (Shadow price = ) rRUS - dRUS ≥ 0
3. RRS Procurement: (Shadow price = ) rRRS - dRRS ≥ 0

**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: (Shadow price = ) g - LSL ≥ 0
2. HSL Constraint: (Shadow price = ) HSL - g - rRUS - rRRS - rSOR ≥ 0
3. SOR capacity constraint: (Shadow price = ) rSOR - g' ≥ 0
4. SOR dispatch constraint: (Shadow price = ) x -u - g' = 0

**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 g, rRUS, rRRS, rSOR, 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,we get:

1. For the expected energy award, g:

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 the energy dispatch from SOR capacity for each x, g':

If the energy dispatch *i* is marginal to the power balance constraint, then, and the energy offer *i* sets the shadow price for the SOR dispatch constraint.

1. For the RegUp award, rRUS:

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 (RegUp MCPC )

1. For the RRS award, rRRS:

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 (RRS MCPC )

1. For the SOR award, rSOR:

Or, substituting from above:

If the SOR offer *i* is marginal to the SOR Procurement constraint, then, and the marginal cost of the capacity offer plus the expected marginal cost of energy offer equals the expected shadow price of SOR dispatch constraint.

**MCPC**

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| --- | --- | --- |
| AS Product | MCPC | Comments |
| RegUp |  | Shadow price of the RegUp procurement constraint |
| RegDn |  | Shadow price of the RegDn procurement constraint |
| RRS |  | Shadow Price of the RRS procurement constraint |
| SOR |  | Expected value of the Shadow Prices of the SOR capacity constraints |