Standardized Contracts with Swing for the Market-Supported Procurement of Energy and Reserve

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Presentation outline

- Motivation & related research
- Potential advantages of standardized contracts with swing
- Example template for standardized contracts with swing
- Standardized contract trading via linked DAM/RTM markets
- Numerical example

Main Reference:
Deung-Yong Heo and Leigh Tesfatsion, “Facilitating Appropriate Compensation of Electric Energy and Reserve Through Standardized Contracts with Swing, *Journal of Energy Markets* 8(4), 2015, 93-121. Working Paper version:
www2.econ.iastate.edu/tesfatsi/StandardizedContracts.HeoTesfatsion.WP13018.pdf

Motivation: Important needs in current power markets

- Need better ways to compensate flexibility in energy/reserve provision

  - Flexibility increasingly important with increased penetration of variable energy resources (VERs) such as wind and solar power

  - Appropriate compensation difficult under current market rules

- Need to ensure an even playing field for all market participants

  - VERs, energy storage devices (ESDs), load-serving entities (LSEs), demand response resources (DRRs), thermal generators, ...

  - Rigid requirements of service provision hinder market participation

- Need to reduce dependence on out-of-market (OOM) compensation

  - OOM increases the complexity of market rules

  - OOM increases opportunities for gaming of market rules

The importance of flexible energy/reserve provision

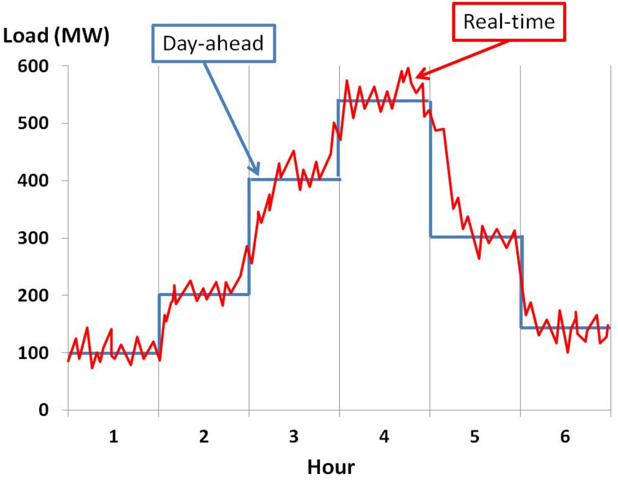


Figure 1: Day-ahead generation scheduling vs. real-time load-balancing needs

Previous related research

1. S.S. Oren, Generation adequacy via call options obligations: Safe passage to the promised land, *Energy J.* 18(9), 2005, 28-42.

   - Suggests heavier reliance on option contracts (two-part pricing)

2. L.S. Tesfatsion, C.A. Silva-Monroy, V.W. Loose, J.F. Ellison, R.T. Elliott, R.H. Byrne, R.T. Guttromson, New Wholesale Power Market Design Using Linked Forward Markets, *Sandia Report SAND2013-2789*, Sandia National Laboratories, April 2013.

   - Conceptual study
   - Proposes separate contract forms (with swing) for energy & reserve
   - Proposes linked forward markets to support contract trading

Potential advantages of standardized contracts with swing

Standardized contracts with swing (flexibility) in contractual terms

- Permit offering of flexibility in service provision
- Function as forward contracts for securing future availability of energy and reserve services
- Function as blueprints for efficient balancing of real-time net load
- Permit two-part pricing for appropriate market compensation of availability and performance
  - Compensation for service *availability* via contract offer price
  - Compensation for services *performed* via performance payment method included among contractual terms

Standardized contract with swing: Example template

$$\mathrm{SC} \;=\; [k, d, T_{ex}, T_{pb}, T_{pe}, R_C, P_C, \phi]$$

$k =$ Location where down/up power delivery is to occur

$d =$ Direction (down or up)

$T_{ex} = [t_{ex}^{min}, t_{ex}^{max}] =$ Interval of possible exercise times t_{ex}

$T_{pb} = [t_{pb}^{min}, t_{pb}^{max}] =$ Interval of possible controlled power begin times t_{pb}

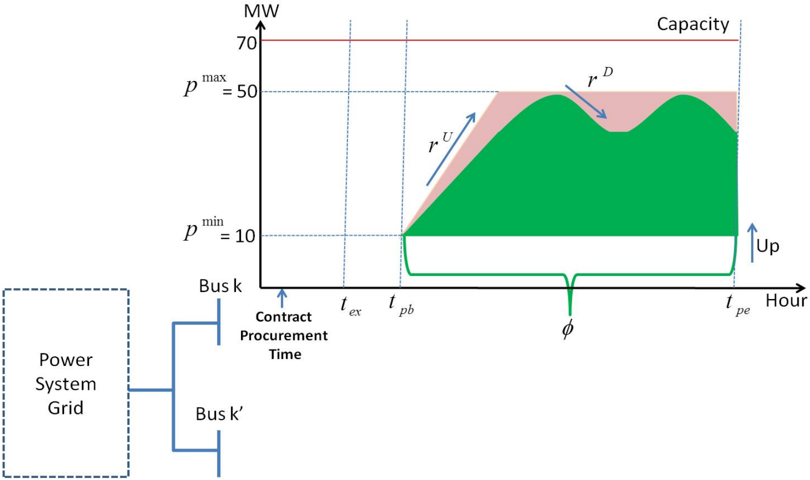
$T_{pe} = [t_{pe}^{min}, t_{pe}^{max}] =$ Interval of possible controlled power end times t_{pe}

$R_C = [-r^D, r^U] =$ Interval of possible controlled down/up ramp rates r

$P_C = [p^{min}, p^{max}] =$ Interval of possible controlled power levels p

$\phi =$ Performance payment method for real-time service performance

Example: Standardized contract with power & ramp swing



Hierarchical structure of SC forms

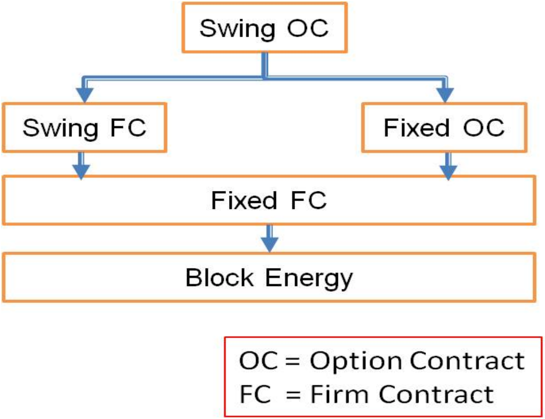


Figure 2: Nested hierarchy of SCs

Two-part pricing of SCs

- SC issuers can seek appropriate *ex-ante* compensation for *flexible service availability* through their *SC offer prices*

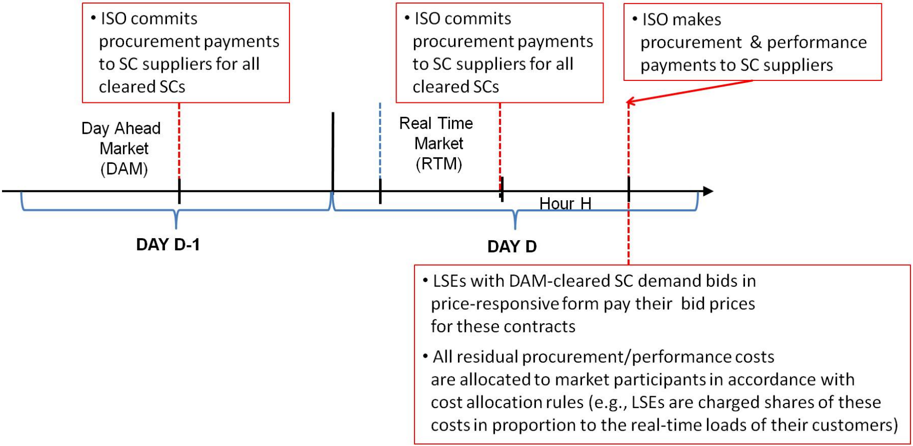
- SC issuers can seek appropriate *ex-post* compensation for *flexible service performance* through their *performance payment methods* ϕ
  - Each SC includes a performance payment method ϕ among its contractual terms

SC trading via linked day-ahead and real-time markets

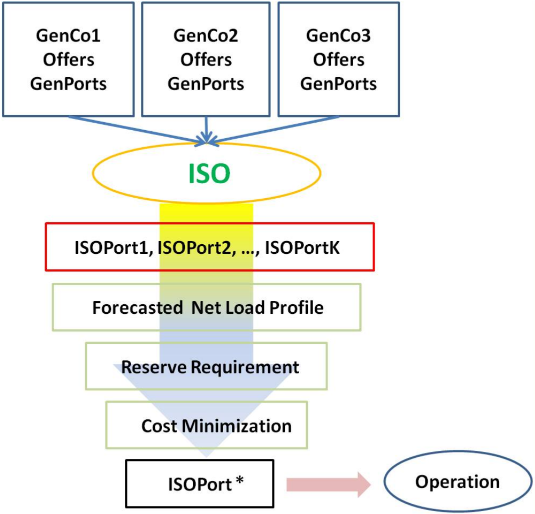
Market Type	Participants	Contracts	Decision Variables	ISO Optimization Method
Day-Ahead Market (DAM)	LSEs	SC Block-Energy Bids	LSE SC Bids; Disp. GenCo / DRR / ESD SC Offers; ISO SC Bids	Security-Constrained Unit Commitment (SCUC) & Security-Constrained Economic Dispatch (SCED)
	Disp. GenCos, DRRs, and ESDs	SC Offers		
	Non-Disp. VERs	—		
	ISO	SC Bids		
Real-Time Market (RTM)	Disp. GenCos, DRRs, and ESDs	SC Offers	Disp. GenCo / DRR / ESD SC Offers; ISO SC Bids	SCED
	Non-Disp. VERs	—		
	ISO	SC Bids		

Figure 3: Proposed ISO-managed day-ahead and real-time markets

SC settlement time-line for operating hour H



RTM operations with SC trading: Numerical example



GenCo: Generation Company

GenPort : Portfolio of SCs

GenPort = {SC1 ,…., SCj}

ISOPort: Portfolio of GenPorts

ISOPort = {Genport1,x ,…., GenPort3,y}

ISO can choose at most one GenPort from each GenCo to construct each ISOPort

DAM and RTM linkages: Numerical example

- Optimal ISOPort selection in the RTM takes the form

  $$\text{ISOPort}^* = \{\text{GenPort}_1^*, \text{GenPort}_2^*, \text{GenPort}_3^* \mid \text{Contract Inventory}\}$$

- *Contract Inventory* = All SCs previously procured in the DAM.

- Expected total avoidable cost of ISOPort* consists of two parts:

  (i) Expected performance payments arising from the expected exercise and/or use of the SCs in the contract inventory;

  (ii) Procurement payments and expected performance payments arising from the RTM-procurement of the SCs comprising GenPort$_1^*$, GenPort$_2^*$, and GenPort$_3^*$.

Note: The DAM procurement cost is a sunk cost at the time of the RTM.

Optimal RTM ISOPort selection: Numerical example

- RTM occurs immediately prior to operating hour H on day D
- For simplicity of exposition, assume no line congestion, no line losses, and no price-sensitive load

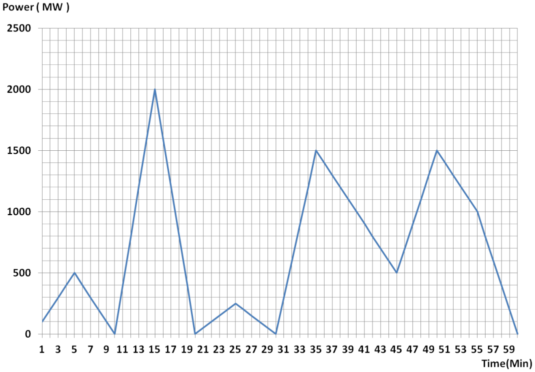


Figure 4: RTM ISO-forecasted net load profile for hour H of day D

RTM numerical example...continued

- RTM participants: Three dispatchable GenCos, non-dispatchable Variable Energy Resources (VERs), and an ISO

- Physical attributes of the three dispatchable GenCos:

$$\mathrm{G1}: \; r_1^D = r_1^U = 120\mathrm{MW/min}, \mathrm{Cap}_1^{min} = 0\mathrm{MW}, \; \mathrm{Cap}_1^{max} = 600\mathrm{MW}$$
$$\mathrm{G2}: \; r_2^D = r_2^U = 200\mathrm{MW/min}, \mathrm{Cap}_2^{min} = 0\mathrm{MW}, \; \mathrm{Cap}_2^{max} = 700\mathrm{MW}$$
$$\mathrm{G3}: \; r_3^D = r_3^U = 300\mathrm{MW/min}, \mathrm{Cap}_3^{min} = 0\mathrm{MW}, \; \mathrm{Cap}_3^{max} = 900\mathrm{MW}$$

- ISO objective:
  - Minimize expected total costs subject to power balance constraints, reserve requirements, and ISO-forecasted net load profile

RTM numerical example...continued

- Assume all SC performance payment methods take the simple form of a specified energy price ϕ (\$/MWh)

G1's supply offer includes two GenPorts, each with one SC:

$$\text{GenPort}_{1,1} = \{\text{SC}_{1,1}\} \text{ at offer price } \text{v}_{1,1}, \tag{1}$$
$$\text{SC}_{1,1} = [t_{pb} = 0,\ t_{pe} = 60,\ |r| \leq 100,\ 0 \leq p \leq 500,\ \phi = 100]$$
$$\text{GenPort}_{1,2} = \{\text{SC}_{1,2}\} \text{ at offer price } \text{v}_{1,2}, \tag{2}$$
$$\text{SC}_{1,2} = [t_{pb} = 0,\ t_{pe} = 60,\ |r| \leq 120,\ 0 \leq p \leq 500,\ \phi = 105].$$

RTM numerical example...continued

G2's supply offer includes three GenPorts with multiple SCs:

$$\mathrm{GenPort}_{2,1} = \{\mathrm{SC}_{2,1,1}, \mathrm{SC}_{2,1,2}\} \text{ at offer price } \mathrm{v}_{2,1}, \tag{3}$$

$$\mathrm{SC}_{2,1,1} = [t_{pb} = 10,\ t_{pe} = 20,\ |r| \leq 200,\ 0 \leq p \leq 600,\ \phi = 135]$$

$$\mathrm{SC}_{2,1,2} = [t_{pb} = 30,\ t_{pe} = 60,\ |r| \leq 200,\ 0 \leq p \leq 600,\ \phi = 130]$$

$$\mathrm{GenPort}_{2,2} = \{\mathrm{SC}_{2,2,1}, \mathrm{SC}_{2,2,2}, \mathrm{SC}_{2,2,3}\} \text{ at offer price } \mathrm{v}_{2,2}, \tag{4}$$

$$\mathrm{SC}_{2,2,1} = [t_{pb} = 0,\ \ t_{pe} = 10,\ |r| \leq 100,\ 0 \leq p \leq 100, \phi = 105]$$

$$\mathrm{SC}_{2,2,2} = [t_{pb} = 10,\ t_{pe} = 20,\ |r| \leq 200,\ 0 \leq p \leq 600, \phi = 135]$$

$$\mathrm{SC}_{2,2,3} = [t_{pb} = 30,\ t_{pe} = 60,\ |r| \leq 200,\ 0 \leq p \leq 600, \phi = 130]$$

$$\mathrm{GenPort}_{2,3} = \{\mathrm{SC}_{2,3,1}, \mathrm{SC}_{2,3,2}, \mathrm{SC}_{2,3,3}\} \text{ at offer price } \mathrm{v}_{2,3}, \tag{5}$$

$$\mathrm{SC}_{2,3,1} = [t_{pb} = 0,\ t_{pe} = 10,\ |r| \leq 100,\ 0 \leq p \leq 100,\ \phi = 105]$$

$$\mathrm{SC}_{2,3,2} = [t_{pb} = 10,\ t_{pe} = 20,\ |r| \leq 200,\ 0 \leq p \leq 700,\ \phi = 140]$$

$$\mathrm{SC}_{2,3,3} = [t_{pb} = 30,\ t_{pe} = 60,\ |r| \leq 200,\ 0 \leq p \leq 700,\ \phi = 135]$$

RTM numerical example...continued

G3's supply offer includes two GenPorts, each with three SCs:

$$\begin{aligned}
\mathrm{GenPort}_{3,1} =& \{\mathrm{SC}_{3,1,1}, \mathrm{SC}_{3,1,2}, \mathrm{SC}_{3,1,3}\} \text{ at offer price } \mathrm{v}_{3,1}, \qquad (6)\\
&\mathrm{SC}_{3,1,1} = [t_{pb} = 10,\ t_{pe} = 20,\ |r| \leq 300,\ 0 \leq p \leq 900,\ \phi = 175]\\
&\mathrm{SC}_{3,1,2} = [t_{pb} = 33,\ t_{pe} = 39,\ |r| \leq 200,\ 0 \leq p \leq 400,\ \phi = 155]\\
&\mathrm{SC}_{3,1,3} = [t_{pb} = 48,\ t_{pe} = 54,\ |r| \leq 200,\ 0 \leq p \leq 400,\ \phi = 155]\\
\mathrm{GenPort}_{3,2} =& \{\mathrm{SC}_{3,2,1}, \mathrm{SC}_{3,2,2}, \mathrm{SC}_{3,2,3}\} \text{ at offer price } \mathrm{v}_{3,2}, \qquad (7)\\
&\mathrm{SC}_{3,2,1} = [t_{pb} = 10,\ t_{pe} = 20,\ |r| \leq 300,\ 0 \leq p \leq 900,\ \phi = 175]\\
&\mathrm{SC}_{3,2,2} = [t_{pb} = 30,\ t_{pe} = 39,\ |r| \leq 200,\ 0 \leq p \leq 400,\ \phi = 150]\\
&\mathrm{SC}_{3,2,3} = [t_{pb} = 44,\ t_{pe} = 54,\ |r| \leq 200,\ 0 \leq p \leq 400,\ \phi = 150]
\end{aligned}$$

Power balance constraint for ISO

- ISO's forecasted net load profile for operating hour H must be balanced.

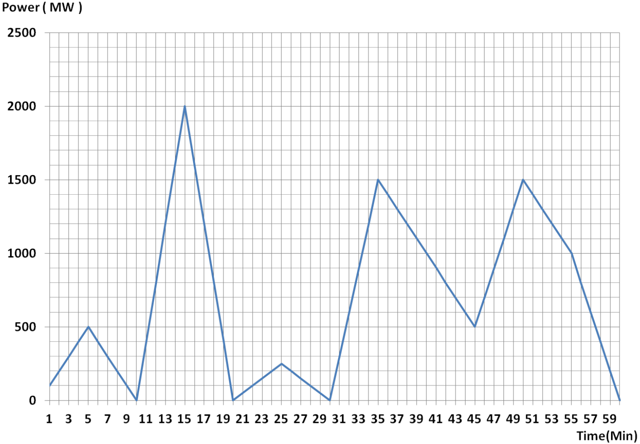


Figure 5: ISO-forecasted net load profile for hour H

Power balance constraint for ISO ... continued

- Cleared ISOPort must achieve a *Zero Balance Gap (ZBG)* for hour H

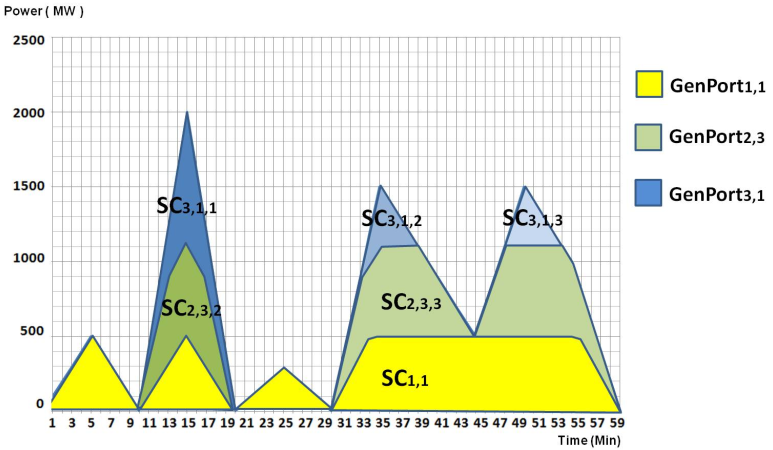


Figure 6: ZBG achieved by $\text{ISOPort}_2 = (\text{GenPort}_{1,1}, \text{GenPort}_{2,3}, \text{GenPort}_{3,1})$

Characterization of an optimal ISOPort

- Multiple ISOPorts might be able to achieve a ZBG.
- Attaining a ZBG is a necessary but not sufficient condition for an ISOPort to be optimal.
- ISO must also consider the "reserve range" and expected total cost of an ISOPort

Reserve Range (RR) inherent in ISOPorts with swing

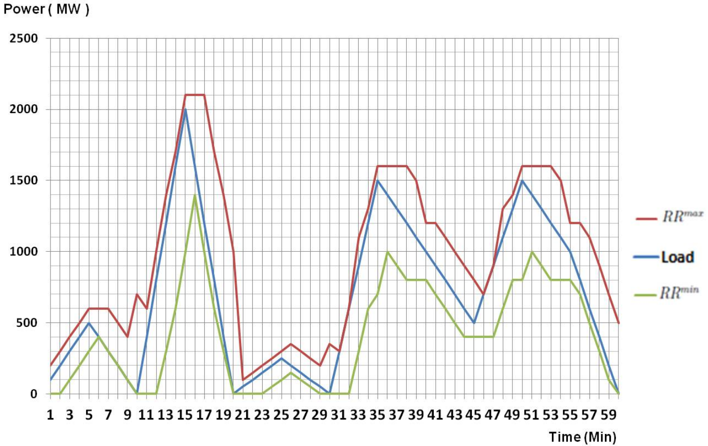


Figure 7: Reserve Range (RR) for ISOPort_2 during hour H of day D

Reserve range constraint for ISO

- *Reserve Range $RR(\boldsymbol{\alpha}^*)$* = Power corridor around ISO-forecasted net load profile L^F with width determined by $\boldsymbol{\alpha}^* = (\alpha^{D*}, \alpha^{U*})$
- The required amount of down-power reserve is determined by α^{D*} and the required amount of up-power reserve is determined by α^{U*}
- For each operating minute M:

$$\mathrm{RR}_M(\boldsymbol{\alpha}^*) = [\mathrm{RR}_M^{\min}(\boldsymbol{\alpha}^*), \mathrm{RR}_M^{\max}(\boldsymbol{\alpha}^*)]$$

$$\mathrm{RR}_M^{\min}(\boldsymbol{\alpha}^*) \leq [1 - \alpha^{D*}]L_M^F \leq L_M^F \leq [1 + \alpha^{U*}]L_M^F \leq \mathrm{RR}_M^{\max}(\boldsymbol{\alpha}^*)$$

Expected total cost of ISOPort

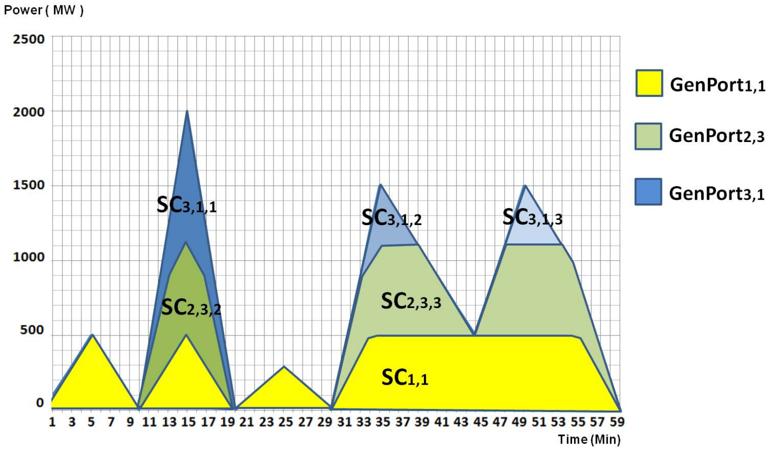
- Expected total cost of ISOPort $=$ (GenPort_1, GenPort_2, GenPort_3) satisfying ZBG and RR($\boldsymbol{\alpha}^*$) constraints consists of:

  (i) the *portfolio offer prices* $\{v_1, v_2, v_3\}$ paid to G1, G2, and G3 for GenPort_1, GenPort_2, and GenPort_3

  (ii) the *expected total performance payments* to be paid to G1, G2, and G3 for energy to satisfy the ZBG constraint.

Calculation of expected total performance payments for an ISOPort

- Shaded Area(SC) $\times$ $\phi(SC)$ $=$ expected performance payment (SC)



ISOPort optimization $\rightarrow$ energy/reserve co-optimization

- ISOPort expected total cost minimization subject to ZBG and RR($\boldsymbol{\alpha}^*$) constraints ensures energy/reserve co-optimization for hour H:
  - The ZBG constraint ensures balancing of the ISO forecasted net load profile for hour H
  - The RR($\boldsymbol{\alpha}^*$) constraint ensures sufficient availability of generation capacity to cover a power corridor around the ISO-forecasted net load profile for hour H whose width is determined by $\boldsymbol{\alpha}^*$

Summary of key findings for the SC system

- permits full, separate, market-based compensation for service availability and service performance (FERC Order 755)
- facilitates a level playing field for market participation.
- facilitates co-optimization of energy and reserve markets
- supports forward-market trading of energy and reserve
- permits resource providers to offer flexible service availability.
- provides system operators with real-time flexibility in service usage

Summary of key findings for the SC system ... continued

- facilitates accurate load forecasting and following of dispatch signals
- permits resources to internally manage UC and capacity constraints
- permits the robust-control management of uncertain net load
- eliminates the need for out-of-market payment adjustments
- reduces the complexity of market rules

Future work

- Seek efficient solution methods for SC robust-control optimization
  - ISO's optimal choice of an SC portfolio (ISOPort) for an operating day D is a *topological covering problem*
  - Requires minimizing the expected total cost of covering an appropriate reserve range $\mathrm{RR}_k(\alpha^*)$ around the forecasted net load profile for each bus k
- Undertake detailed SC system studies to test
  - feasibility
  - efficiency (non-wastage of resources)
  - reliability (security/adequacy)
  - robustness against strategic manipulation