Facilitating Appropriate Compensation of Electric Energy and Reserve through Standardized Contracts with Swing

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Presentation outline:

- Background motivation & previous related research
- Potential advantages of standardized contracts: Overview
- Basic form of standardized energy/reserve contracts with swing
- Standardized contract trading via linked DAM/RTM markets
- Numerical example

Working Paper:

Deung-Yong Heo and Leigh Tesfatsion, "Energy and Reserve Procurement Through Standardized Contracts in Linked Electricity Markets: Illustrative Examples," Economics Department, Iowa State U, WP No. 13018, Nov. 2013, Revised June 2014.
www.econ.iastate.edu/tesfatsi/StandardizedContracts.HeoTesfatsion.WP13018.pdf

Motivation: Important needs in current power markets

- Better ways to compensate flexibility in energy/reserve provision

  - Flexibility increasingly important with renewable energy penetration

  - Adequate compensation difficult under current market rules

- Reducing 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:

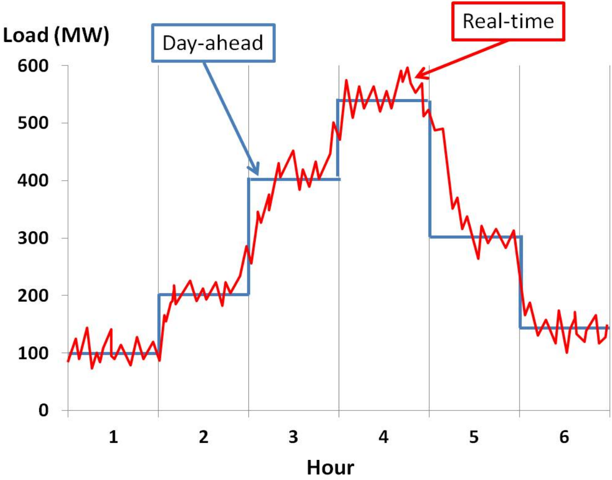


Figure 1: Day-ahead generation scheduling vs. real-time load-balancing needs

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: Overview

- A *swing* contract permits the issuer to offer one or more services in a flexible manner

  Example: The contact issuer offers to provide power between max and min values within a specified range of ramp rates

As argued in Tesfatsion et al. (*Sandia Report*, 2013):

- Standardized contracts with swing can function as *financial contracts* ensuring the *joint* availability of energy and reserve services

- Standardized contracts with swing can function as *blueprints* for efficient real-time load balancing

Standardized energy/reserve contracts with swing: An illustrative example

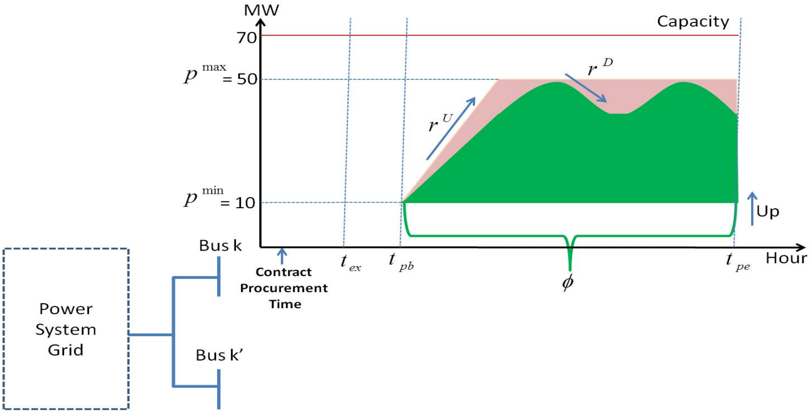


Figure 2: Adapted from [2] Tesfatsion et al., *Sandia Report*, 2013

Potential advanges of standardized contracts...continued:

- The two-part pricing of standardized energy/reserve contracts with swing results in an efficient settlement system less susceptible to gaming than two-settlement LMP systems

  Ex-Ante: Compensation for service *availability* via offer price

  Ex-Post: Compensation for services *performed* via performance payment method included among contractual terms

- A recent study (Heo/Tesfatsion, Working Paper, 2014) provides a proof-of-concept for these claims by means of concrete examples

Standardized energy/reserve contract with swing (SC): Basic form

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

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

ϕ = Performance payment method for real-time generation performance

Illustrative example: Redux

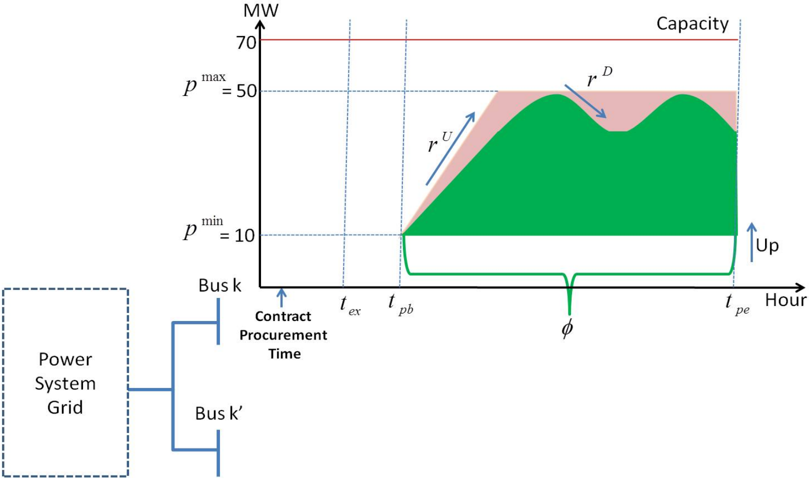


Figure 3: Adapted from [2] Tesfatsion et al., *Sandia Report*, 2013

Hierarchical structure of standardized contract (SC) forms:

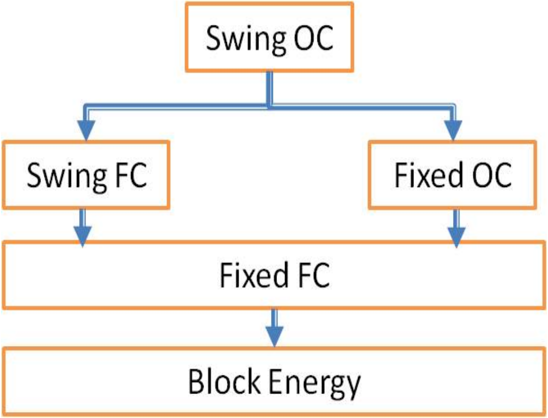


Figure 4: Nested hierarchy of SCs

Hierarchical structure of SC forms...continued:

- A *firm contract (FC)* is a non-contingent contract that requires specific performance from both counterparties.

- An *option contract (OC)* gives the holder the right, but not the obligation, to exercise the contract at stated times.
  - Once exercised, an OC imposes specific performance obligations on both counterparties.

Hierarchical structure of SC forms...continued:

- An FC or OC is said to be a *fixed* contract if all of its contractual terms are designated as point values.

- An FC or OC is said to be a *swing* contract if at least one of its contractual terms is designated as a range of values, thus permitting some degree of flexibility in its implementation.

- A fixed FC is said to be a *block-energy* contract if its contractual terms obligate the issuer to maintain a specified constant power level during a specified time interval.

An SC with swing permits flexibly-offered energy/reserve services whether it takes a firm or option form

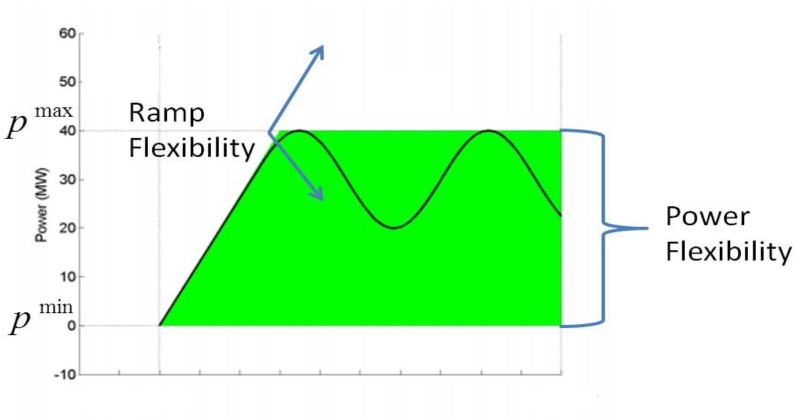


Figure 5: *Example:* Flexibly offered power and ramping under a firm SC

Two-part pricing of SCs:

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

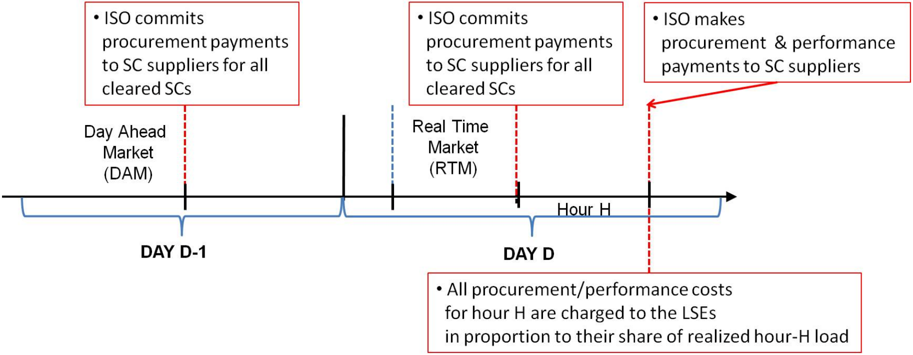
- SC issuers can seek appropriate *ex-post* compensation for *flexible service performance* through their *performance payment methods* ϕ
  - Each SC includes a performance payment method ϕ among its contractual terms

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

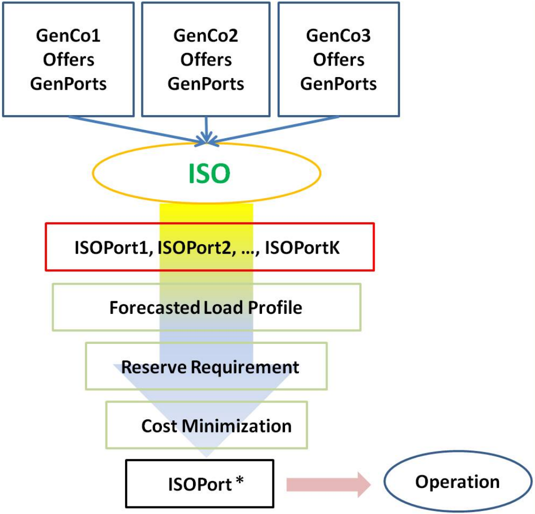
Market Type	Participants	Contracts	Decision Variables	ISO Optimization Method
Day-Ahead Market (DAM)	LSEs GenCos, DRRs, and ESDs ISO	Block-Energy Bids SC Offers SC Bids	LSE SC Bids; GenCo / DRR / ESD SC Offers; ISO SC Bids (for Reserve Purposes).	Security-Constrained Unit Commitment (SCUC) & Security-Constrained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

Figure 6: Proposed ISO-managed day-ahead and real-time markets

Envisioned SC settlement time-line:



Market operations with SC trading: 3-GenCo illustration



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: 3-GenCo illustration

- 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) Performance payments arising from the exercise and/or use of the previously procured SCs in the contract inventory;

  (ii) Portfolio offer prices and expected performance payments arising from the RTM-procurement of the SCs comprising GenPort_1^*, GenPort_2^*, and GenPort_3^*.

Note: The contract inventory *DAM procurement* cost is a sunk cost.

Optimal RTM ISOPort selection: Numerical 3-GenCo example

- RTM occurs immediately prior to operating hour H on day D
- No transmission congestion, price-responsive load, or line losses

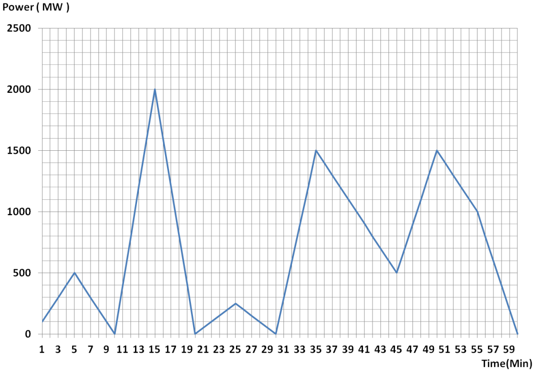


Figure 7: RTM ISO-forecasted load profile for hour H of day D

RTM numerical example...continued:

- RTM participants include three GenCos and an ISO

- Physical attributes of the three GenCos:

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

- ISO Objective:
  - Minimize expected total costs subject to power balance constraints, reserve requirements, and ISO-forecasted 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:

$$\text{GenPort}_{1,1} = \{\text{SC}_{1,1}\} \text{ at offer price } \text{v}_{1,1}, \quad (1)$$

$$\text{SC}_{1,1} = [t_{pb} = 0,\ t_{pe} = 60,\ |r| \leq 100,\ 0 \leq p \leq 500,\ \phi = 100]$$

$$\text{GenPort}_{1,2} = \{\text{SC}_{1,2}\} \text{ at offer price } \text{v}_{1,2}, \quad (2)$$

$$\text{SC}_{1,2} = [t_{pb} = 0,\ t_{pe} = 60,\ |r| \leq 120,\ 0 \leq p \leq 500,\ \phi = 105].$$

RTM numerical example...continued:

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

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

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

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

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

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

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

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

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

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

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

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

RTM numerical example...continued:

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

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

Power balance constraint for ISO:

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

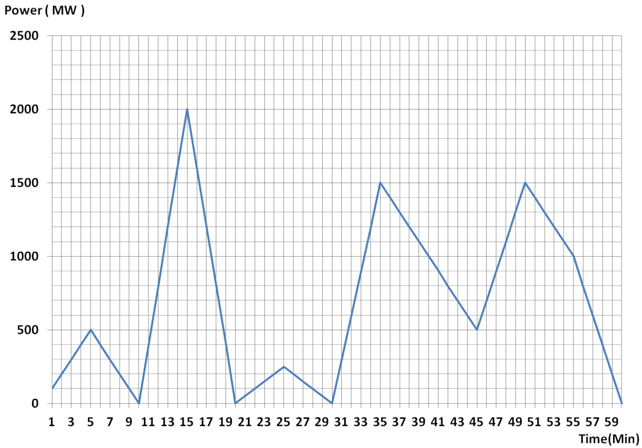


Figure 8: ISO-forecasted load profile for hour H

Power balance constraint for ISO:

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

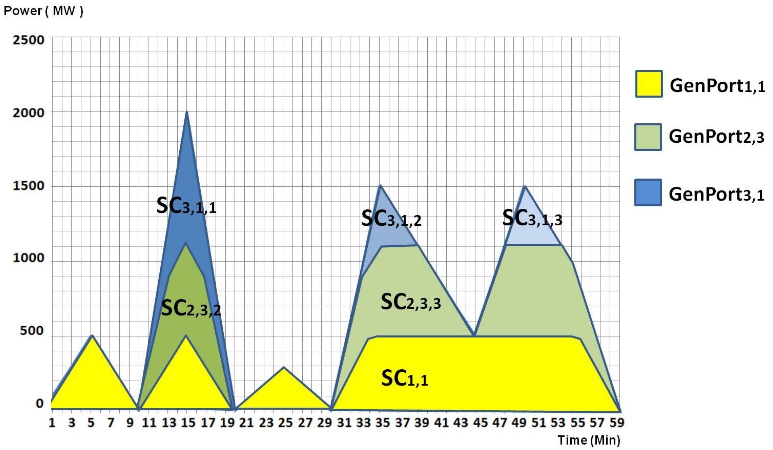


Figure 9: ZBG achieved by $\text{ISOPort}_2 = (\text{GenPort}_{1,1}, \text{GenPort}_{2,3}, \text{GenPort}_{3,1})$

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 inherent in ISOPorts with swing:

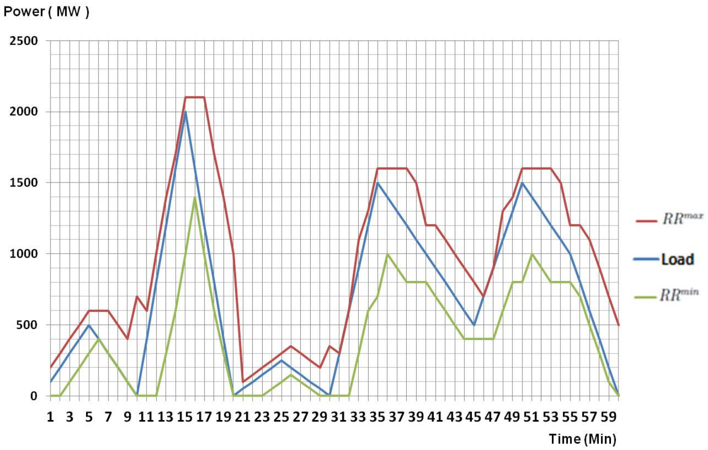


Figure 10: Reserve Range (RR) for $ISOPort_2$ during hour H of day D

Reserve Range (RR) constraint for ISO:

- *Reserve Range RR($\boldsymbol{\alpha}^*$)* $=$ Power corridor around ISO-forecasted load profile L^F with width determined by $\boldsymbol{\alpha}^* = (\alpha^{D*}, \alpha^{U*})$

- For each operating minute M:

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

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

- 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*}

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

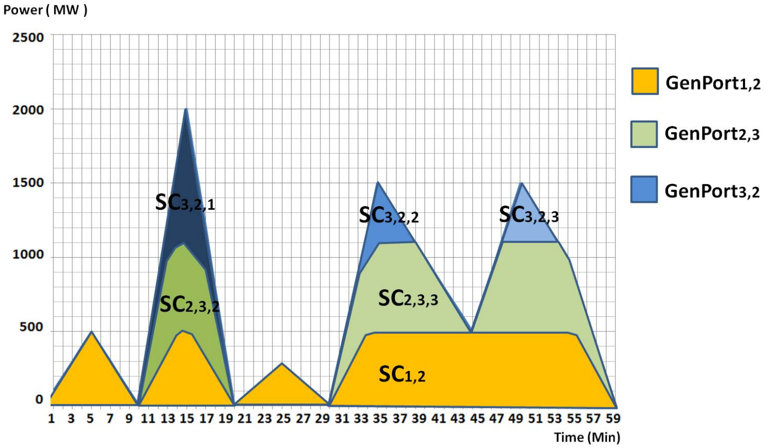
- Expected total cost of ISOPort = (GenPort_1, GenPort_2, GenPort_3) satisfying ZBG and RR($\boldsymbol{\alpha}^*$) constraints consists of:

  (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 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 load profile for hour H whose width is determined by $\boldsymbol{\alpha}^*$

Optimal RTM ISOPorts with transmission congestion

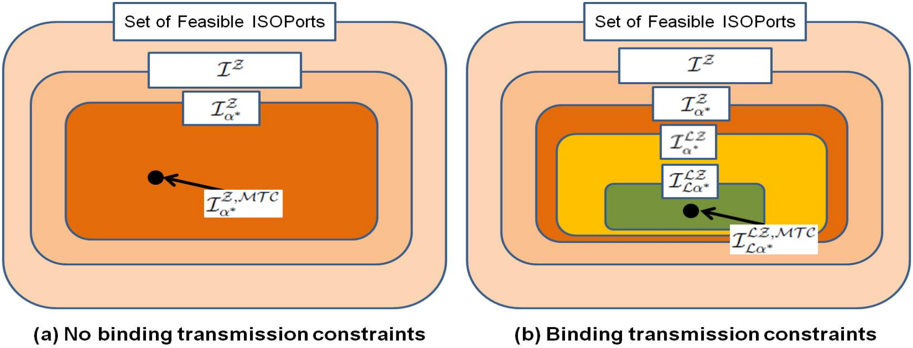


Figure 11: Depiction of the subsets $\mathcal{I}^{\mathcal{Z},\mathcal{MTC}}_{\alpha^*}$ and $\mathcal{I}^{\mathcal{LZ},\mathcal{MTC}}_{\mathcal{L}\alpha^*}$ of optimal ISOPorts subject to (a) system-wide ZBG constraints and system-wide RR($\boldsymbol{\alpha}^*$) constraints in the absence of binding transmission constraints, and (b) local ZBG constraints and local RR($\boldsymbol{\alpha}^*$) constraints in the presence of binding transmission constraints.

Summary of key findings:

- SCs in option form can function as reserve products whether or not they have swing in their contractual terms.
- SCs with swing in their contractual terms can function as both energy and reserve products, even if they are firm contracts.
- SCs with swing in their contractual terms permit flexible provision of services critical for real-time load-balancing, such as:
  - power start times
  - down/up ramp rates
  - down/up power levels
  - power stop times

Summary of key findings...continued:

- SCs are financial contracts whose trading can be supported by linked day-ahead and real-time markets (DAM/RTM)

- Two-part pricing of SCs can replace DAM/RTM pricing by LMPs
  - The procurement price of an SC, determined through market processes, compensates the SC issuer for a guarantee of service availability
  - The performance payment method of an SC (included among its contractual terms) determines compensation for services rendered

- SCs are blueprints for achieving efficient real-time load balancing subject to power balance and reserve requirement constraints

- SCs permit load uncertainties to be handled via power-corridor covering, a robust-control alternative to stochastic optimization requiring detailed load scenarios and load-scenario probabilities

Planned Future Work:

- New mathematical challenge: Optimal choice of an ISOPort for an operating day D can be expressed as a *topological covering problem*:
  - Minimize the expected total cost of ensuring coverage of a power corridor RR(α^*) around the forecasted load profile for day D
  - A form of statistical robust control
- Detailed simulation studies are needed to test the proposed new contract and market formulations with regard to:
  - feasibility
  - efficiency (non-wastage of resources)
  - reliability (security/adequacy)
  - robustness against strategic manipulation