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

Leigh Tesfatsion$^a$,* and Deung-Yong Heo$^b$

$^a$Iowa State University and $^b$Korea Institute of Local Finance

*Presenter (tesfatsi@iastate.edu)

IEEE PES GM 2015
Sheraton Denver Downtown Hotel, Denver, CO
10am-12 noon, Governor’s Square 12
30 July 2015
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

References:

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

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

   - 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

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

\( k \) = Location where down/up power delivery is to occur

\( d \) = Direction (down or up)

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

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

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

\[ R_C = [r^D, r^U] = \text{Interval of possible controlled down/up ramp rates } r \]

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

\( \phi \) = 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

- Swing OC
  - Swing FC
  - Fixed FC
    - Block Energy
  - Fixed OC

OC = Option Contract
FC = Firm Contract
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*.
  - Each SC includes a performance payment method among its contractual terms.
### SC trading via linked day-ahead and real-time markets

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**Figure 3:** Proposed ISO-managed day-ahead and real-time markets
SC settlement time-line for operating hour H

- ISO commits procurement payments to SC suppliers for all cleared SCs

Day Ahead Market (DAM)

- ISO commits procurement payments to SC suppliers for all cleared SCs

Real Time Market (RTM)

- ISO makes procurement & performance payments to SC suppliers

Hour H

- LSEs with DAM-cleared SC demand bids in price-responsive form pay their bid prices for these contracts
- All residual procurement/performance costs are allocated to market participants in accordance with cost allocation rules (e.g., LSEs are charged shares of these costs in proportion to the real-time loads of their customers)
RTM operations with SC trading: Numerical example

- GenCo1 Offers GenPorts
- GenCo2 Offers GenPorts
- GenCo3 Offers GenPorts

ISO

ISOPort1, ISOPort2, ..., ISOPortK

Forecasted Net Load Profile

Reserve Requirement

Cost Minimization

ISOPort *

Operation

GenCo: Generation Company

GenPort: Portfolio of SCs

GenPort = \{SC1, \ldots, SCj\}

ISOPort: Portfolio of GenPorts

ISOPort = \{Genport1,x, \ldots, 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

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

- \textit{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^*.

\textbf{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:

  G1: \( r_1^D = r_1^U = 120\text{MW/min} \), \( \text{Cap}_{1}^{\min} = 0\text{MW} \), \( \text{Cap}_{1}^{\max} = 600\text{MW} \)
  G2: \( r_2^D = r_2^U = 200\text{MW/min} \), \( \text{Cap}_{2}^{\min} = 0\text{MW} \), \( \text{Cap}_{2}^{\max} = 700\text{MW} \)
  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 net load profile
RTM numerical example...continued

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

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

GenPort_{1,1} = \{SC_{1,1}\} at offer price $v_{1,1}$,

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

GenPort_{1,2} = \{SC_{1,2}\} at offer price $v_{1,2}$,

\[
SC_{1,2} = [t_{pb} = 0, \ t_{pe} = 60, \ |r| \leq 120, \ 0 \leq p \leq 500, \ \phi = 105].
\]
RTM numerical example...continued

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

\[ \text{GenPort}_{2,1} = \{\text{SC}_{2,1,1}, \text{SC}_{2,1,2}\} \text{ at offer price } v_{2,1}, \]
\[ \text{SC}_{2,1,1} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 135] \]
\[ \text{SC}_{2,1,2} = [t_{pb} = 30, \ t_{pe} = 60, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 130] \]

\[ \text{GenPort}_{2,2} = \{\text{SC}_{2,2,1}, \text{SC}_{2,2,2}, \text{SC}_{2,2,3}\} \text{ at offer price } v_{2,2}, \]
\[ \text{SC}_{2,2,1} = [t_{pb} = 0, \ t_{pe} = 10, \ |r| \leq 100, \ 0 \leq p \leq 100, \ \phi = 105] \]
\[ \text{SC}_{2,2,2} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 135] \]
\[ \text{SC}_{2,2,3} = [t_{pb} = 30, \ t_{pe} = 60, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 130] \]

\[ \text{GenPort}_{2,3} = \{\text{SC}_{2,3,1}, \text{SC}_{2,3,2}, \text{SC}_{2,3,3}\} \text{ at offer price } v_{2,3}, \]
\[ \text{SC}_{2,3,1} = [t_{pb} = 0, \ t_{pe} = 10, \ |r| \leq 100, \ 0 \leq p \leq 100, \ \phi = 105] \]
\[ \text{SC}_{2,3,2} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 200, \ 0 \leq p \leq 700, \ \phi = 140] \]
\[ \text{SC}_{2,3,3} = [t_{pb} = 30, \ t_{pe} = 60, \ |r| \leq 200, \ 0 \leq p \leq 700, \ \phi = 135] \]
RTM numerical example...continued

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

\[ \text{GenPort}_{3,1} = \{ \text{SC}_{3,1,1}, \text{SC}_{3,1,2}, \text{SC}_{3,1,3} \} \text{ at offer price } v_{3,1}, \]

\[ \text{SC}_{3,1,1} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 300, \ 0 \leq p \leq 900, \ \phi = 175] \]
\[ \text{SC}_{3,1,2} = [t_{pb} = 33, \ t_{pe} = 39, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 155] \]
\[ \text{SC}_{3,1,3} = [t_{pb} = 48, \ t_{pe} = 54, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 155] \]

\[ \text{GenPort}_{3,2} = \{ \text{SC}_{3,2,1}, \text{SC}_{3,2,2}, \text{SC}_{3,2,3} \} \text{ at offer price } v_{3,2}, \]

\[ \text{SC}_{3,2,1} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 300, \ 0 \leq p \leq 900, \ \phi = 175] \]
\[ \text{SC}_{3,2,2} = [t_{pb} = 30, \ t_{pe} = 39, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 150] \]
\[ \text{SC}_{3,2,3} = [t_{pb} = 44, \ t_{pe} = 54, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 150] \]
Power balance constraint for ISO

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

Figure 5: RTM ISO-forecasted net load profile for hour H of day D
Figure 6: ZBG achieved by 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 $RR(\alpha^*) = \text{Power corridor around ISO-forecasted net load profile } L^F \text{ with width determined by } \alpha^* = (\alpha^D, \alpha^U)$

- The required amount of down-power reserve is determined by $\alpha^D$ and the required amount of up-power reserve is determined by $\alpha^U$

- For each operating minute $M$:

  \[ RR_M(\alpha^*) = [RR^\text{min}_M(\alpha^*), RR^\text{max}_M(\alpha^*)] \]

  \[ RR^\text{min}_M(\alpha^*) \leq [1 - \alpha^D]L^F_M \leq L^F_M \leq [1 + \alpha^U]L^F_M \leq RR^\text{max}_M(\alpha^*) \]
Expected total cost of ISOPort

- Expected total cost of ISOPort $= (\text{GenPort}_1, \text{GenPort}_2, \text{GenPort}_3)$ satisfying ZBG and RR($\alpha^*$) 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) = \text{expected performance payment (SC)}
ISOPort optimization $\rightarrow$ energy/reserve co-optimization

- ISOPort expected total cost minimization subject to ZBG and RR($\alpha^*$) 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($\alpha^*$) 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 $\alpha^*$
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 service 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 $RR_k(\alpha^*)$ 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
On-Line Resources


**Note:** A shortened version of this working paper is forthcoming in *Journal of Energy Markets*.

- Integrated Retail and Wholesale (IRW) Power Systems Project Homepage
  [http://www2.econ.iastate.edu/tesfatsi/IRWProjectHome.htm](http://www2.econ.iastate.edu/tesfatsi/IRWProjectHome.htm)

- Deung-Yong Heo’s CV
  [https://sites.google.com/site/deungyongheo/cv](https://sites.google.com/site/deungyongheo/cv)

- Leigh Tesfatsion’s Homepage
  [http://www2.econ.iastate.edu/tesfatsi/](http://www2.econ.iastate.edu/tesfatsi/)