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

Deung-Yong Heo and Leigh Tesfatsion

3 May 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

Working Paper:
Motivation: Important needs in current power markets

- Need better ways to compensate flexibility in energy/reserve provision
  - Flexibility increasingly important with renewable energy penetration
  - Adequate compensation difficult under current market rules

- 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

- Need an even playing field for market participants
  - Rigid requirements of service provision hinder market participation
Summary of key findings

- The standardized contract (SC) system permits separate full market-based compensation for service availability and service performance.

- The SC system facilitates a level playing field for resource participation.

- The SC system facilitates energy/reserve co-optimization.

- The SC system facilitates forward energy/reserve trading.

- The SC system permits resources to offer flexible service availability.

- The SC system permits market operators to have real-time flexibility in service usage.
Summary of key findings ... continued

- The SC system permits resources to internally manage unit commitment and generation-capacity constraints.

- The SC system permits resources to internally manage unit commitment and generation-capacity constraints.

- The SC system permits a robust-control management of uncertainties.

- The SC system eliminates need for out-of-market payment adjustments.

- The SC system reduces the complexity 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 (SCs) with swing ...

- Permit offering of flexibility in service provision

  Ex) Issuer offers to provide power between max and min values within a specified range of ramp rates

- Can function as physical contracts ensuring the joint availability of energy and reserve services

- Can function as blueprints for efficient real-time net load
The two-part pricing of standardized energy/reserve contracts with swing results in an efficient settlement:

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

**Ex-Post:** 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

- 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 procure services from the issuer under contractually specified terms.
  - Once exercised, an OC imposes specific performance obligations on both counterparties.
Hierarchical structure of SC forms...continued

- An FC or OC is a *fixed* contract if each of its contractual terms is designated as a single possible value.

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

- A fixed FC is a *block-energy* contract if its contractual terms obligate the issuer to maintain a specified constant power level during a specified time interval.
Hierarchical structure of SC forms ... continued

Figure 2: Nested hierarchy of SCs

Swing OC

Swing FC

Fixed OC

Fixed FC

Block Energy

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* $\phi$.
  - Each SC includes a performance payment method $\phi$ among its contractual terms.
SC trading via linked day-ahead and real-time markets

**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)

**DAY D-1**

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

Real Time Market (RTM)

**DAY D**

- ISO makes procurement & performance payments to SC suppliers

- 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: 3-GenCo illustration

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 = \{SC_1, ..., SC_j\}

ISOPort: Portfolio of GenPorts
ISOPort = \{Genport_1, x, ..., GenPort_3, 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

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

- \textit{Contract Inventory} = \text{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 3-GenCo example

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

**Figure 4:** RTM ISO-forecasted net load profile for hour H of day D
RTM numerical example...continued

- RTM participants include three dispatchable GenCos; non-dispatchable VERs; and an ISO

- Physical attributes of the three dispatchable GenCos:

  G1: \( r_D^1 = r_U^1 = 120\text{MW/min}, \) \( \text{Cap}_{min}^1 = 0\text{MW, } \text{Cap}_{max}^1 = 600\text{MW} \)

  G2: \( r_D^2 = r_U^2 = 200\text{MW/min}, \) \( \text{Cap}_{min}^2 = 0\text{MW, } \text{Cap}_{max}^2 = 700\text{MW} \)

  G3: \( r_D^3 = r_U^3 = 300\text{MW/min}, \) \( \text{Cap}_{min}^3 = 0\text{MW, } \text{Cap}_{max}^3 = 900\text{MW} \)

- ISO objective:

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

1. $\text{GenPort}_{1,1} = \{\text{SC}_{1,1}\}$ at offer price $v_{1,1}$,
   
   $\text{SC}_{1,1} = [t_{pb} = 0, t_{pe} = 60, |r| \leq 100, 0 \leq p \leq 500, \phi = 100]$. (1)

2. $\text{GenPort}_{1,2} = \{\text{SC}_{1,2}\}$ at offer price $v_{1,2}$,
   
   $\text{SC}_{1,2} = [t_{pb} = 0, t_{pe} = 60, |r| \leq 120, 0 \leq p \leq 500, \phi = 105]$. (2)
G2’s supply offer includes three GenPorts with multiple SCs:

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

\[
SC_{2,1,1} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 135] \\
SC_{2,1,2} = [t_{pb} = 30, \ t_{pe} = 60, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 130]
\]

GenPort_{2,2} = \{SC_{2,2,1}, SC_{2,2,2}, SC_{2,2,3}\} at offer price \(v_{2,2}\),

\[
SC_{2,2,1} = [t_{pb} = 0, \ t_{pe} = 10, \ |r| \leq 100, \ 0 \leq p \leq 100, \ \phi = 105] \\
SC_{2,2,2} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 135] \\
SC_{2,2,3} = [t_{pb} = 30, \ t_{pe} = 60, \ |r| \leq 200, \ 0 \leq p \leq 600, \ \phi = 130]
\]

GenPort_{2,3} = \{SC_{2,3,1}, SC_{2,3,2}, SC_{2,3,3}\} at offer price \(v_{2,3}\),

\[
SC_{2,3,1} = [t_{pb} = 0, \ t_{pe} = 10, \ |r| \leq 100, \ 0 \leq p \leq 100, \ \phi = 105] \\
SC_{2,3,2} = [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 200, \ 0 \leq p \leq 700, \ \phi = 140] \\
SC_{2,3,3} = [t_{pb} = 30, \ t_{pe} = 60, \ |r| \leq 200, \ 0 \leq p \leq 700, \ \phi = 135]
\]
G3's supply offer includes two GenPorts, each with three SCs:

\[
\text{GenPort}_{3,1} = \{ \text{SC}_{3,1,1}, \text{SC}_{3,1,2}, \text{SC}_{3,1,3} \} \text{ at offer price } v_{3,1}, \tag{6}
\]

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

\[
\text{GenPort}_{3,2} = \{ \text{SC}_{3,2,1}, \text{SC}_{3,2,2}, \text{SC}_{3,2,3} \} \text{ at offer price } v_{3,2}, \tag{7}
\]

\[
\begin{align*}
\text{SC}_{3,2,1} &= [t_{pb} = 10, \ t_{pe} = 20, \ |r| \leq 300, \ 0 \leq p \leq 900, \ \phi = 175] \\
\text{SC}_{3,2,2} &= [t_{pb} = 30, \ t_{pe} = 39, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 150] \\
\text{SC}_{3,2,3} &= [t_{pb} = 44, \ t_{pe} = 54, \ |r| \leq 200, \ 0 \leq p \leq 400, \ \phi = 150]
\end{align*}
\]
ISO’s forecasted net load profile for operating hour H must be balanced.

Figure 5: ISO-forecasted net load profile for hour H
Cleared ISOPort must achieve a Zero Balance Gap (ZBG) for hour H

Figure 6: ZBG achieved by ISOPort_2 = (GenPort_{1,1}, GenPort_{2,3}, 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\textsubscript{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) × φ(SC) = 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

- The SC system permits separate full market-based compensation for service availability and service performance.

- The SC system facilitates a level playing field for resource participation.

- The SC system facilitates energy/reserve co-optimization.

- The SC system facilitates forward energy/reserve trading.

- The SC system permits resources to offer flexible service availability.

- The SC system permits market operators to have real-time flexibility in service usage.
Summary of key findings ... continued

• The SC system permits resources to internally manage unit commitment and generation-capacity constraints.

• The SC system permits resources to internally manage unit commitment and generation-capacity constraints.

• The SC system permits a robust-control management of uncertainties.

• The SC system eliminates need for out-of-market payment adjustments.

• The SC system reduces the complexity of market rules.
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 $RR(\alpha^*)$ around the forecasted net load profile for day D

- 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