Market Provision of Flexible Energy/Reserve Contracts

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Presentation Outline

- Motivation
- What is a *Swing Contract*?
- *Swing Contract Market Design*: Distinct Features
- Optimal Market Clearing Formulation
- Numerical Illustration
- Conclusion

Motivation

- Need for flexible service provision is growing
  - Increased penetration of variable energy resources
  - Greater uncertainty in customer demand
- Swing contracts permit flexible service provision
  - Permit *bundling* of multiple service attributes (power, ramp, duration…) within a single contract
  - Permit each service attribute to be offered with *flexibility (swing)* in its implementation range
  - Permit separate market-based compensation for service *availability* and for actual real-time service *performance*

Illustrative Swing Contract (SC)

Offered Contractual Terms

$$\mathrm{SC} = [b, t_s, t_e, \mathcal{P}, \mathcal{R}, \phi]$$

b = location where service delivery is to occur;

t_s = power delivery start time;

t_e = power delivery end time;

$\mathcal{P} = [P^{min}, P^{max}]$ = range of power levels p;

$\mathcal{R} = [-R^D, R^U]$ = range of down/up ramp rates r;

ϕ = Performance payment method for real-time services.

Swing (flexibility) is offered in both the power level p and the ramp rate r

α = Availability price

= Payment requested by SC issuer for ensuring service availability

Numerical Example:

Note: A very simple type of performance payment method ϕ is illustrated here.

α = \$100

b = bus b;

t_s = 8:00am;

t_e = 10:00am;

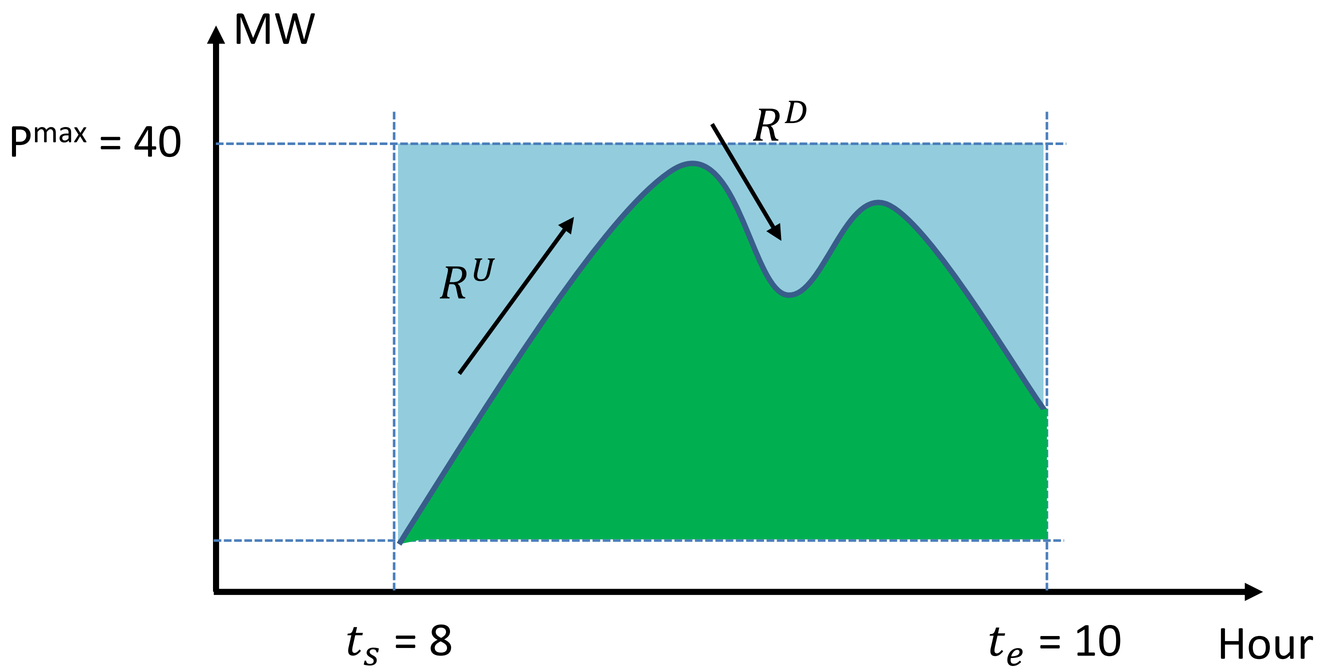
$\mathcal{P} = [P^{min}, P^{max}]$ = [10MW, 40MW];

$\mathcal{R} = [-R^D, R^U]$ = [-38MW/h, 28MW/h];

ϕ = \$35/MWh.

Depiction of SC Numerical Example

Swing Contract (SC):



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$\phi = \$35/\text{MWh}$.

Note: The above figure depicts one possible power path a day-ahead market operator could dispatch in real time, in accordance with the terms of this SC. The green area is the resulting delivery of energy (MWh), compensated ex post at $35/MWh.

Day-Ahead Market (DAM) Comparison

		Current DAM	Proposed SC DAM
Similarities		• Conducted day-ahead to plan for next-day operations • ISO-managed • MPs can include GenCos, LSEs, DRAs, ESDs, & VERs • Subject to same physical constraints: e.g. transmission, generation, ramping, & power-balance constraints	
Differences	• Optimization formulation	SCUC & SCED	Contract-clearing
	• Settlement	Locational marginal pricing	Contract-determined prices
	• Payment	Payment for next-day service before actual performance	Payment for availability now & performance ex post
	• Out-of-market payments	Uplift payments (e.g., for UC)	No
	• Information released to MPs	UC, DAM LMPs, & next-day dispatch schedule	Which contracts have been cleared

DAM Comparison Continued…Optimization Formulations

		SCUC	SCED	SC Contract Clearing
Similarities		• Both SCUC & SC contract clearing are solved as mixed integer linear programming (MILP) problems subject to physical constraints		
Differences	• Objective	Min {Start-Up /Shut-Down Costs + No-Load Costs + Dispatch Costs + Reserve Costs}	Min {Dispatch Costs + Reserve Costs}	Min {Availability Cost + Expected Performance Cost}
	• Start-up & shut-down constraints	Yes	No	Start-up/shut-down constraints are implicit in submitted contracts
	• Key decision variables	Unit Commitment vector	Energy dispatch & reserves	Cleared contracts
	• Settlement		LMPs calculated as SCED dual variables	Availability prices paid for cleared contracts

New MILP Optimization Formulation (Li & Tesfatsion, GM 2016)

ISO's Optimization Problem for SC Market:

$$\underset{c,p}{\text{Minimize}} \sum_{m\in\mathcal{M}} \alpha_m c_m + \sum_{t\in T}\sum_{m\in\mathcal{M}} \phi_m(t)|p_m(t)|\Delta t$$

Total SC availability cost + Total expected SC performance cost

Subject to :

- Unit commitment constraints
- Transmission constraints
- Power balance constraints
- Capacity constraints
- Down/up ramping constraints
- System-wide down/up reserve requirements

m: Index for market participants with dispatchable services

t: Hour index

Input data:

α_m: Availability price for m's SC offer

$\phi_m(t)$: Hour-t performance price in m's SC offer

$NL_b(t)$: Net load forecast for bus b in hour t

$RR^D(t)$, $RR^U(t)$: System-wide down/up reserve requirements for hour t

ISO Decision variables:

c_m: m's SC offer cleared or not (1/0)

$p_m(t)$: Power output for m in hour t

Unit Commitment Constraints for SC DAM

c_m: m's SC offer cleared or not (1/0)
$v_m(t)$: UC vector, (1/0)
$A_m(t)$: Binary input, 1 if t is within contract service period, 0 otherwise

Unit commitment constraints:

$$v_m(t) = c_m \cdot A_m(t), \qquad \forall\, m \in \mathcal{M},\ t \in T$$

The unit commitment $v_m(t) \in \{0, 1\}$ for each market participant $m \in \mathcal{M}$ in each period t is determined by two factors:

(a) Is m's SC offer cleared by the ISO? → c_m
(b) Does m's SC offer include service for hour t? → $A_m(t)$

Example:

Illustrative SC was given for a market participant *m* that offers power from 8:00am to 10:00am. Thus, for this *m:*

$$A_m(t) = \begin{cases} 1 & \text{if } t \in \{8, 9, 10\} \\ 0 & \text{if } t \in \{1, \ldots, 7\} \cup \{11, \ldots, 24\} \end{cases}$$

Transmission Constraints for SC DAM

Voltage angle specification at angle reference bus 1:

$$\theta_1(t) = 0, \qquad \forall t \in T$$

Line power constraints:

$$w_\ell(t) = S_0 B(\ell)\left[\theta_{s(\ell)}(t) - \theta_{e(\ell)}(t)\right],$$
$$-\pi \leq \theta_b(t) \leq \pi, \ \forall b \in \mathcal{B}, \ell \in \mathcal{L}, \ t \in T$$

Transmission constraints:

$$-F_\ell^{max} \leq w_\ell(t) \leq F_\ell^{max}, \qquad \forall \ell \in \mathcal{L}, \ t \in T$$

SC DAM Constraints Continued…

- Power balance constraints: $$\sum_{m \in \mathcal{M}_b} p_m(t) + \sum_{\ell \in \mathcal{L}_b} w_\ell(t) = NL_b(t), \ \forall b \in \mathcal{B}, \ t \in T$$

- Capacity constraints:
$$\underline{p}_m(t) \leq p_m(t) \leq \bar{p}_m(t), \qquad \forall m \in \mathcal{M}, \ t \in T$$
$$\bar{p}_m(t) \leq P_m^{max} v_m(t), \qquad \forall m \in \mathcal{M}, \ t \in T$$
$$\underline{p}_m(t) \geq P_m^{min} v_m(t), \qquad \forall m \in \mathcal{M}, \ t \in T$$

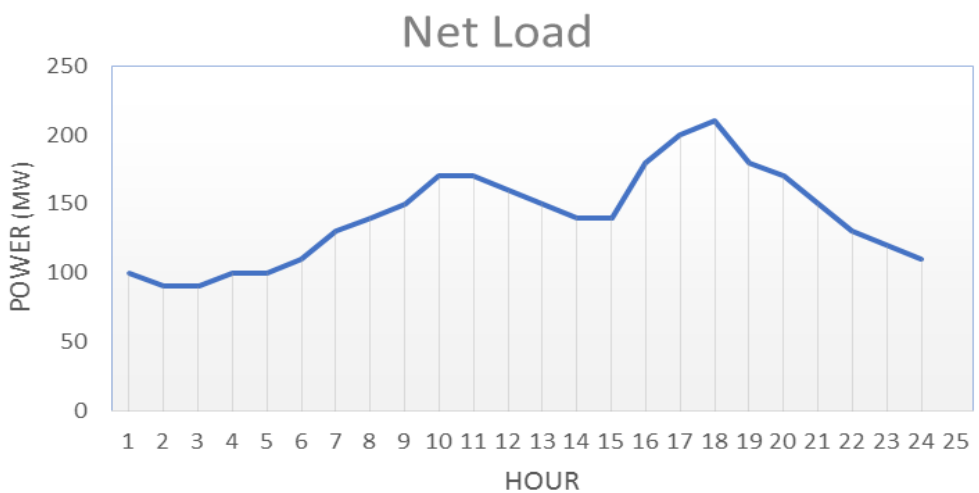
- Down/up ramping constraints:
$$\bar{p}_m(t) - p_m(t-1) \leq R_m^U \Delta t v_m(t-1) + P_m^{max}[1 - v_m(t-1)]$$
$$\forall m \in \mathcal{M}, \ \forall t = 2, \cdots, |T|$$
$$p_m(t-1) - \underline{p}_m(t) \leq R_m^D \Delta t \cdot v_m(t) + P_m^{max}[1 - v_m(t)]$$
$$\forall m \in \mathcal{M}, \ \forall t = 2, \cdots, |T|$$

- System-wide reserve requirements:
$$\sum_{m \in \mathcal{M}} \bar{p}_m(t) \geq \sum_{b \in \mathcal{B}} NL_b(t) + RR^U(t), \quad \forall t \in T$$
$$\sum_{m \in \mathcal{M}} \underline{p}_m(t) \leq \sum_{b \in \mathcal{B}} NL_b(t) - RR^D(t), \quad \forall t \in T$$

Illustrative 3-GenCo Example: Input Data

TABLE I
SCs SUBMITTED BY THE THREE GENCOS IN THE ILLUSTRATIVE EXAMPLE

GenCo	Service Period $[t_s, t_e]$	Power Range $[P^{min}, P^{max}]$ (MW)	Ramp Rate Range $[-R^D, R^U]$ (MW/h)	Performance Price ϕ ($/MWh)	Availability Price α ($)
1	[1, 24]	[0, 80]	[-60, 60]	25	1500
2	[1, 24]	[0, 200]	[-30, 30]	10	2000
3	[8, 24]	[0, 120]	[-50, 50]	20	1000



Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
NetLoad (MW)	100	90	90	100	100	110	130	140	150	170	170	160	150	140	140	180	200	210	180	170	150	130	120	110

Illustrative 3-GenCo Example: Results

Contract Clearing

GenCo	Cleared Contract
1	0
2	1
3	1

→ Info released to GenCos

Unit Commitment

GenCo	Hours																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Optimal Dispatch Schedule

GenCo	Hours																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	100	90	90	100	100	110	130	140	150	170	170	160	150	140	130	160	190	200	180	170	150	130	120	110
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	10	10	0	0	0	0	0	0

Illustrative 3-GenCo Example: Results…Cont’d

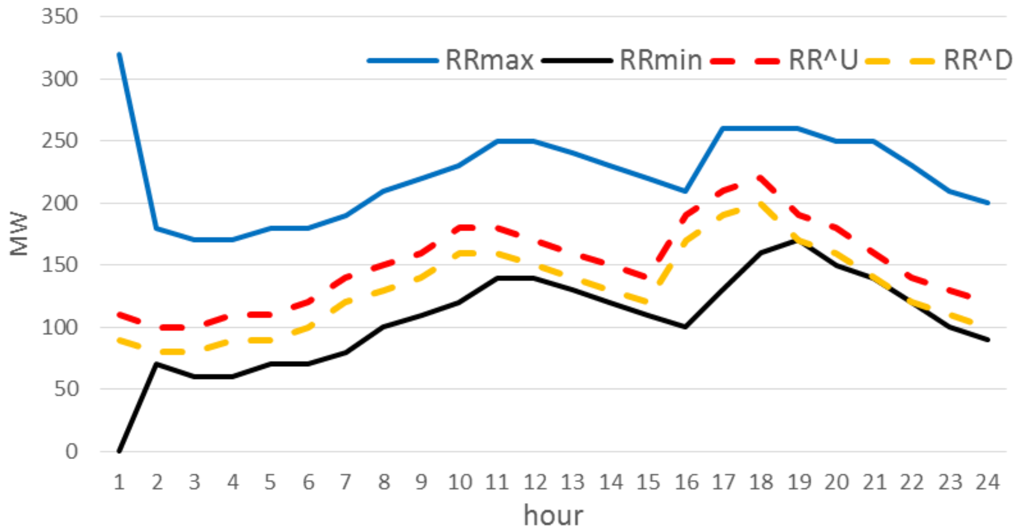
- **Inherent Reserve Range**

$$RR^{max}(t) = \sum_{m \in \mathcal{M}} \overline{p}_m(t) \qquad \forall t \in T$$

$$RR^{min}(t) = \sum_{m \in \mathcal{M}} \underline{p}_m(t) \qquad \forall t \in T$$

The terms $RR^{max}(t)$ and $RR^{min}(t)$ are the maximum and minimum power levels available for the system in hour t *along the solution path*.

The ***inherent reserve range*** for hour t can then be calculated as $RR(t) = [RR^{min}(t), RR^{max}(t)]$.



Solid Lines = Inherent reserve range around the solution path, due to swing

Dotted Lines = Down/up reserve requirements, specified in advance

In conclusion, swing contracts…

- Permit multiple service attributes (power, ramp, duration,…) to be *bundled* together & offered in one contract
- Permit each service attribute to be offered with *swing (flexibility)* in its implementation range
- Permit market-based compensation of service *availability* through SC availability (offer) prices
- Permit market-based ex-post compensation of actual service *performance* thru contractual performance payment methods
- Can be *optimally cleared* within a market context via a mixed integer linear programming (MILP) optimization formulation

Online Resources

[1] Wanning Li & Leigh Tesfatsion, "Market Provision of Flexible Energy/Reserve Contracts: Optimization Formulation," Working Paper #15019, Econ Department, ISU, Nov 2015. To appear in *Proceedings of the PES GM 2016,* Boston, MA.
http://www2.econ.iastate.edu/tesfatsi/MarketProvisionSwingContracts.LiTesfatsion.WP15019.pdf

[2] Deung-Yong Heo & Leigh Tesfatsion, "Facilitating Appropriate Compensation of Electric Energy and Reserve Through Standardized Contracts with Swing," *Journal of Energy Markets* 8(4), December 2015, 93-121 (Presented at FERC Technical Conferences 2014/2015)
http://www2.econ.iastate.edu/tesfatsi/SwingContractsJEMPreprint.HeoTes2015.pdf

[3] Leigh S. Tesfatsion, César A. Silva-Monroy, Verne W. Loose, James F. Ellison, Ryan T. Elliott, Raymond H. Byrne, and Ross T. Guttromson, "New Wholesale Power Market Design Using Linked Forward Markets: A Study for the DOE Energy Storage Systems Program," Sandia Report, SAND2013-2789, Unlimited Release, April 2013. (Sandia/ARPA-E Project)
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