Facilitating Flexible Service Provision in Electric Power Markets via Swing Contracting

Presenter

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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
- References

Motivation

- Need for flexible service provision is increasing
  - Increased penetration of variable energy resources
  - Greater uncertainty in customer demand
- Swing contracts permit flexible service provision
  - Permit bundling of multiple services (power, ramp, duration…) within a single contract
  - Permit each service 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.

α =: Availability price

=: Payment requested by contract issuer for ensuring service availability

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

Numerical Example:

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

α = $100

b = bus b;

t_s = 8:00am;

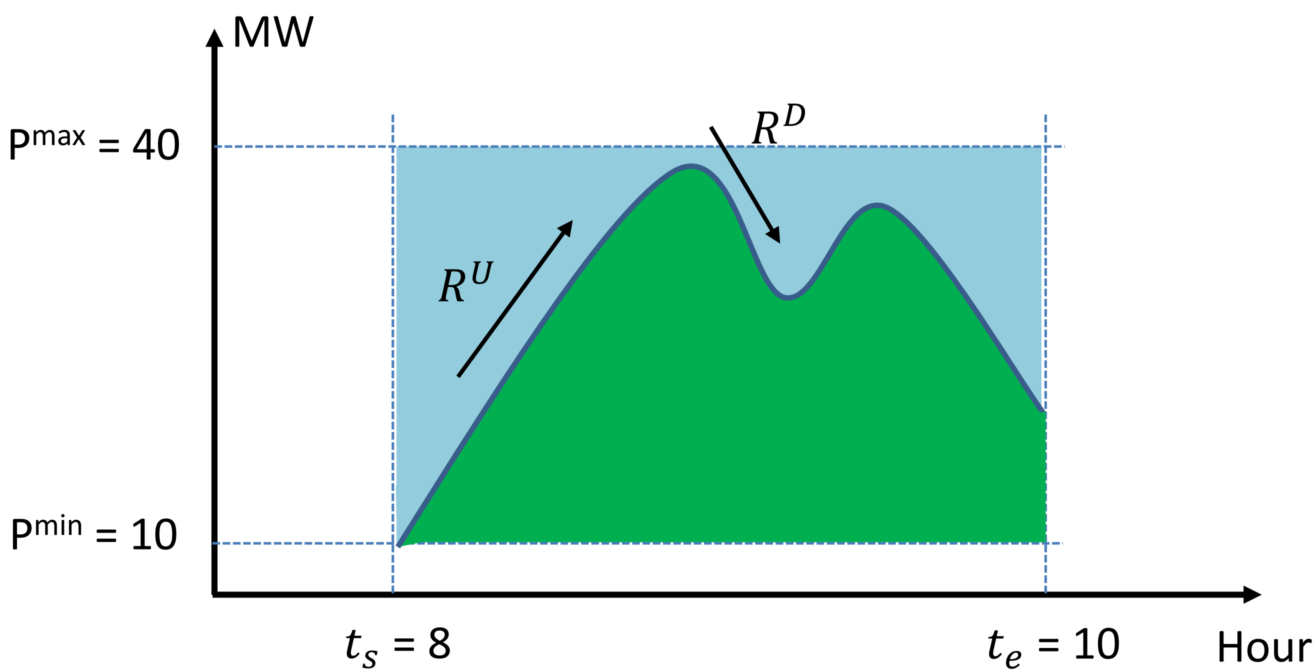
t_e = 10:00am;

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

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

ϕ = \$35/MWh.

Depiction of SC Numerical Example



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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 DRAs, LSEs, GenCos, ESDs, & VERs • Subject to same physical constraints: e.g. transmission, capacity, 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
	• Make-whole payments	Make-whole payments are paid (e.g., for UC)	No make-whole payments are needed or paid
	• 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 system 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

MILP Optimization Formulation (Ref. [2] Li & Tesfatsion, IEEE PES GM 2016)

ISO's Optimization Formulation for SC Market:

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

Total SC availability cost + Total expected SC performance cost

Subject to :

- Unit commitment constraints
- Line power constraints
- Transmission constraints
- Power balance constraints
- Resource capacity constraints
- Resource ramp-up and ramp-down constraints
- System-wide reserve requirement constraints

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:

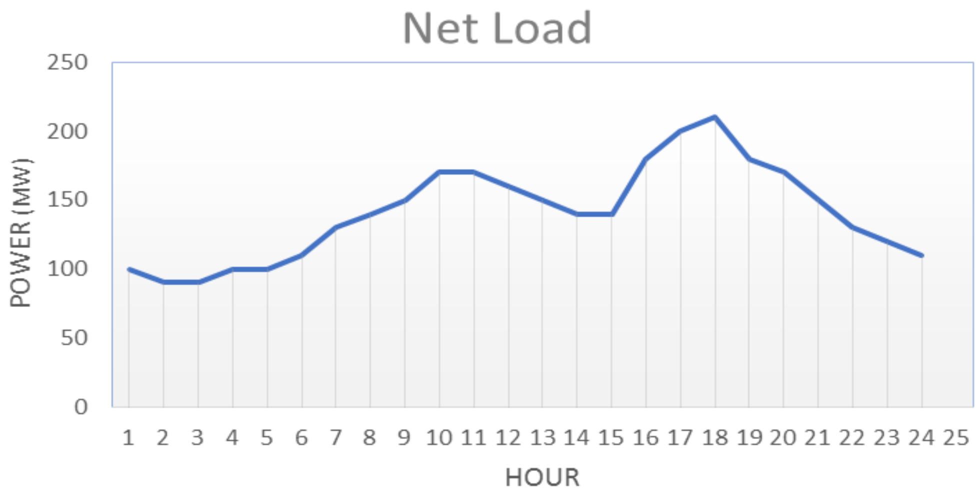
c_m: m's SC offer cleared or not (1/0)

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

Illustrative 3-GenCo Example: Input Data

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	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

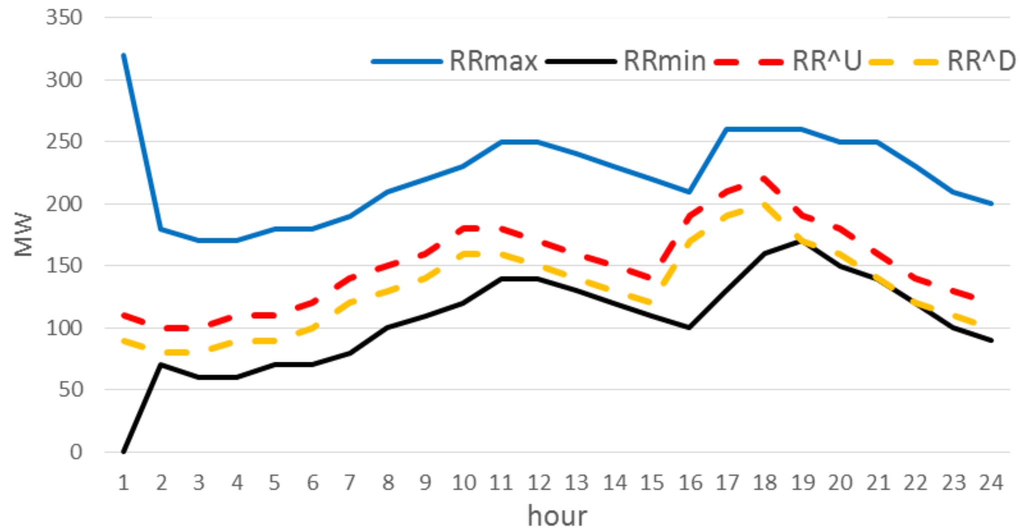
- Inherent Reserve Range

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

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

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 the interval $RR(t)$ =: [$RR^{min}(t)$, $RR^{max}(t)$].



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 types of services (power, ramp, duration,…) to be bundled together and offered in one contract
- Permit each type of service 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
- Contracts can be optimally cleared within a market context using a **M**ixed **I**nteger **L**inear **P**rogramming (**MILP**) optimization formulation

Previous Swing Contract Research

[1] Wanning Li & Leigh Tesfatsion, "A Swing-Contract Market Design for Flexible Service Provision in Electric Power Systems," Economics Working Paper No. 17020, Department of Economics, Iowa State University, February 2017.
https://www2.econ.iastate.edu/tesfatsi/SwingContractMarketDesign.LiTesfatsion.WP17020.pdf

[2] Wanning Li & Leigh Tesfatsion, "Market Provision of Flexible Energy/Reserve contracts: Optimization Formulation," *Proceedings of the IEEE Power and Energy Society General Meeting* (Electronic), Boston, MA, July 17-21, 2016.

[3] 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)
https://www2.econ.iastate.edu/tesfatsi/SwingContractsJEMPreprint.HeoTes2015.pdf

[4] 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)
https://www2.econ.iastate.edu/tesfatsi/MarketDesignSAND2013-2789.LTEtAl.pdf