Self-Commitment of Combined Cycle Units under Electricity Price Uncertainty

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Anthony Papavasiliou (Université catholique de Louvain)
Yi He (Wells Fargo)
Alva Svoboda (PG&E)

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Motivation and Research Objective

Motivation:

- Day-ahead market clearing: **deterministic equivalent** model, **limited horizon**, simplified representation of **combined cycle units**
- Renewable resources $\Rightarrow$ real-time price uncertainty
- Increased utilization of combined-cycle units

Dilemma: should utilities self-commit combined cycle units?

- Benefit: high real time prices $\Rightarrow$ operate at higher mode
- Cost: low real-time prices $\Rightarrow$ no recovery of fixed costs

Motivating Example

- Risk-neutral generator with capacity P, marginal cost C, minimum load cost K, facing uncertain real-time price λ_{RT}
- Without uplift payments, unit stays off if $\lambda_{DA} \leq C + \frac{K}{P}$
- When considering self-commitment, unit solves

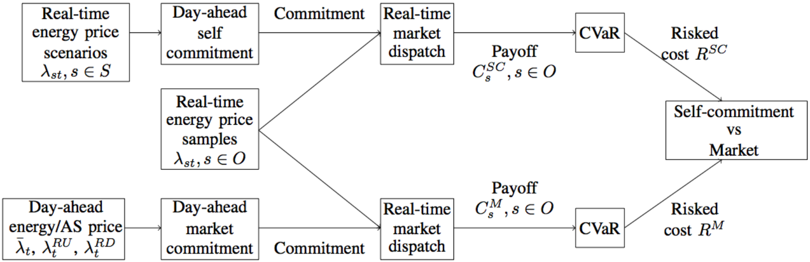
$$\max \mathbb{E}[(\lambda_{RT} - C) \cdot p] - K \cdot u$$
$$0 \leq p \leq P \cdot u$$
$$u \in \{0, 1\}$$

- Condition for self-commitment:

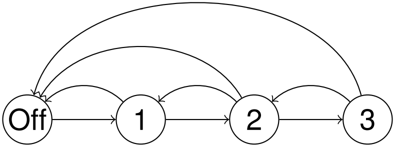
$$C \cdot \mathbb{P}[\lambda_{RT} \geq C] + \frac{K}{P} \leq \mathbb{E}[\lambda_{RT} | \lambda_{RT} \geq C]$$

Conclusion: A generator may want to self-commit despite the day-ahead market keeping them off

Model Setup


Real-time energy price scenarios $\lambda_{st}, s \in S$
Day-ahead self commitment
Commitment
Real-time market dispatch
CVaR
Risked cost R^{SC}
Payoff $C_s^{SC}, s \in O$
Real-time energy price samples $\lambda_{st}, s \in O$
Self-commitment vs Market
Payoff $C_s^{M}, s \in O$
Day-ahead energy/AS price $\bar{\lambda}_t$, λ_t^{RU}, λ_t^{RD}
Day-ahead market commitment
Commitment
Real-time market dispatch
CVaR
Risked cost R^{M}

Combined Cycle Model



- Objective: maximize profits
  - Revenues from selling energy and reserves
  - Fuel costs (non-linear heat rate curve), variable O&M costs, fixed operating costs / transition costs
- States are fired up in sequence, $\leq$ 1 transition per period
- Sales + own demand = production
- Energy and reserves $\leq$ unit capacity
- Ramp rate limits per state
- Min up down/time limits per state and for unit overall

Self-Commitment Model

- Self-commitment introduces risk in the real-time market
- We represent risk using conditional value at risk (CVaR)
- Represent real-time market payoff as $Q(w, \lambda_s)$
  - λ_s: real-time price
  - w: first-stage decisions (unit commitment)
- Rockafellar, Uryasev (2002): CVaR can be computed as

$$\min_{\zeta} \zeta + \frac{1}{1-a} \sum_{s \in S} \pi_s (Q(w, \lambda_s) - \zeta)^+,$$

- Self-commitment problem has following form:

$$\min_{w \in W} c^T w + \zeta + \frac{1}{1-a} \sum_{s \in S} \pi_s (Q(w, \lambda_s) - \zeta)^+$$

$$(P2_s) : Q(w, \lambda_s) = \min_{Aw+Bz=h, z \geq 0} \lambda_s^T z$$

Case Study Assumptions

- 3×1 configuration
- Heat rate curve from typical WECC unit, 6 segments
- 4-hour min up/down times per state, 6-hour overall min up/down times
- Horizon: 48-hours
- Calibrate 2nd order AR model to 2012 CAISO NP15 hub real-time / day-ahead energy prices
- Day-ahead ancillary services prices: 2012 CAISO NP15
- Natural gas prices: 3.11 $/MMBtu (2012 average day-ahead PG&E Citygate hub price)

Study Cases

- We study 4 intervals:
  - (I) Spring weekday-weekend
  - (II) Spring weekday-weekday
  - (III) Summer weekday-weekend
  - (IV) Summer weekday-weekday
- We study 4 levels of risk aversion: $a = 0$ (risk neutral), 0.25, 0.5, 0.75
- We use $|S| = 100$ scenarios for optimization
- We use $|O| = 10,000$ samples for Monte Carlo simulation

Impact of Risk Aversion

Table: 95% confidence intervals of risk-adjusted profits (in $\$ \cdot 10^3$ over the 48-hour horizon)

		Reference prices			
		$a = 0$	0.25	0.50	0.75
(I)	Self-Commit	59.7-64.5	0	0	0
	Market	0	0	0	0
(II)	Self-Commit	60.0-64.4	4.7-6.4	0	0
	Market	0	0	0	0
(III)	Self-Commit	357.4-360.4	334.9-335.9	324.8-325.7	315.8-317.2
	Market	350.4-352.6	327.7-328.2	320.8-321.1	317.4-317.6
(IV)	Self-Commit	414.9-420.9	375.8-376.7	366.2-367.1	359.4-359.6
	Market	390.5-392.6	369.2-369.7	362.8-363.0	359.4-359.6

Impact of Price Volatility

Re-run same analysis with RT / DA market price spread = 150% of reference model

Table: 95% confidence intervals of risk-adjusted profits (in $\$ \cdot 10^3$ over the 48-hour horizon).

		Volatile prices			
		$a = 0$	0.25	0.50	0.75
(I)	Self-Commit	88.2-100.1	23.8-26.7	0	0
	Market	0	0	0	0
(II)	Self-Commit	106.3-113.5	24.0-26.8	0	0
	Market	0	0	0	0
(III)	Self-Commit	402.2-411.7	349.0-350.5	332.0-333.3	317.2-319.3
	Market	379.2-382.7	342.7-343.7	330.4-330.8	323.2-323.5
(IV)	Self-Commit	451.7-460.9	389.2-390.6	372.0-372.5	365.0-365.3
	Market	417.9-421.1	383.6-384.5	372.0-372.5	365.0-365.3

Running Time and Size of the Scenario Set

Day	α	$\|S\|$	Time (sec)	Cuts	Profit ($\$ \cdot 10^3$)
I	0	100	537	100	59.7 - 64.5
I	0	1000	2679	100	59.7 - 64.5
I	0.25	100	588	100	0
I	0.25	1000	2901	100	4.2 - 6.0
I	0.5	100	499	100	0
I	0.5	1000	2522	100	0
I	0.75	100	469	100	0
I	0.75	1000	2343	100	0
II	0	100	532	100	60.0 - 64.4
II	0	1000	2875	100	60.0 - 64.4
II	0.25	100	465	100	4.7 - 6.4
II	0.25	1000	3058	100	4.2 - 6.0
II	0.5	100	387	100	0
II	0.5	1000	2582	100	0
II	0.75	100	456	100	0
II	0.75	1000	2593	100	0

Day	α	$\|S\|$	Time (sec)	Cuts	Profit ($\$ \cdot 10^3$)
III	0	100	229	69	357.4 - 360.4
III	0	1000	2637	100	361.4 - 367.7
III	0.25	100	243	79	334.9 - 335.9
III	0.25	1000	1979	69	334.9 - 335.9
III	0.5	100	190	74	324.8 - 325.7
III	0.5	1000	1526	66	324.8 - 325.7
III	0.75	100	240	93	315.8 - 317.2
III	0.75	1000	2112	86	317.4 - 317.6
IV	0	100	162	65	414.9 - 420.9
IV	0	1000	1534	32	413.3 - 419.4
IV	0.25	100	159	67	375.8 - 376.7
IV	0.25	1000	2045	80	375.8 - 376.7
IV	0.5	100	203	74	366.2 - 367.1
IV	0.5	1000	1844	14	366.2 - 367.1
IV	0.75	100	242	87	359.4 - 359.6
IV	0.75	1000	2591	100	359.4 - 359.6

Conclusions and Perspectives

Conclusions:

- Benefits of self-commitment exist, but decrease with increased risk aversion
- Price volatility can increase the benefit of self-commitment
- Observed differences between DA/RT prices of US markets justify self-commitment

Perspectives:

- Engie (formerly GDF-Suez): Commitment of combined cycle units with off-take constraints (TOP gas contracts)
- Detailed modeling of combined cycle units in ISO models (Guan, forthcoming IEEE TPS)

Thank you

Questions?

anthony.papavasiliou@uclouvain.be

http://www.perso.uclouvain.be/anthony.papavasiliou/public_html

Profit Distribution, Summer Weekday-Weekend

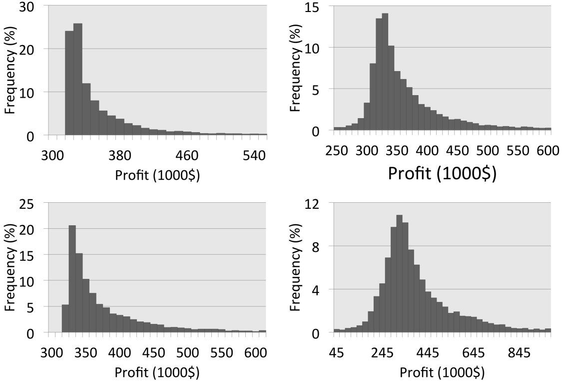
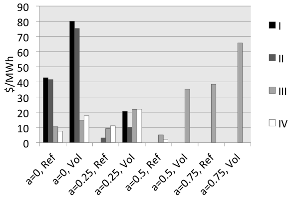


Figure: Market, reference prices (upper left). Self-commitment ($a = 0$), reference prices (upper right). Market, volatile prices (lower left). Self-commitment ($a = 0$), volatile prices (lower right).

Feedback of Real-Time Prices on Self-Commitment

- How low do RT prices have to go to make units indifferent between self-commitment and DA market: 2.2-80$/MWh



- 2009-2012 DA - RT data outside this range:
  - CAISO NP15 hub: -2.37$/MWh to +0.19$/MWh
  - ISO New England Internal hub: -0.66$/MWh to -0.01$/MWh
  - PJM Dominion hub: -0.42$/MWh to +0.59$/MWh
  - New York ISO Capital hub: +0.77$/MWh to +1.43$/MWh
  - MISO Consumer Energy hub: +0.40$/MWh to +1.05$/MWh

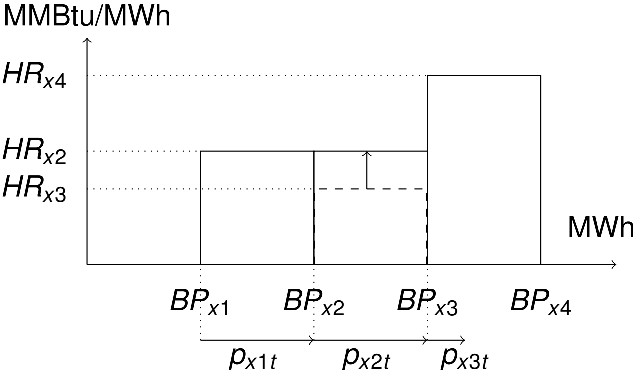
Properties of the Value Function

- The value function $V(w, \zeta) = \sum_{s \in S} \pi_s (Q(w, \lambda_s) - \zeta)^+$ is a **convex** function of (w, ζ)
- The subgradient of $V(w, \zeta)$ at (w, ζ) is given by

$$\partial V(w, \zeta) = \sum_{s \in S} \pi_s 1_s \begin{bmatrix} -\sigma_s^T A \\ -1 \end{bmatrix}$$

  where $1_s = 1_{Q(w, \lambda_s) \geq \zeta}$ and σ_s are the dual optimal multipliers of $Aw + Bz = h$ in $(P2_s)$
- We can apply Benders decomposition

Incremental Heat Rate Curve



Differences Among the Two Policies

Table: Commitment (MW) for self-commitment ($a = 0$) versus day-ahead market, Summer Weekday-Weekday.

Hours	1-21	22 - 28	29 - 32	33-36	37 - 47	48
Self-Commit	1053	1053	1053	1053	1053	0
Market	1053	0	301	602	1053	0

Market shuts unit down in hour 22, restarts in hour 29:

- Startup costs
- Lost profits due to delay (8 hours) for returning to 3×1