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Estimating Potential Revenue from Electrical Energy Storage in PJM

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Background

- Estimating revenue from energy storage is difficult:
 - Different rules for various Independent System Operators (ISO's)/markets
 - Pricing varies by region
 - Non market areas require a different approach (e.g., production cost modeling)
- The goal of the paper was to outline the optimization for PJM and provide an example
- Presented at the IEEE Power and Energy Society (PES) General Meeting, July 2016 (won Prize paper award)

Background

- PJM frequency regulation payment:

$$\text{RMCCP credit} = \text{REG}_t \times \eta_t \times \text{RMCCP}_t$$

$$\text{RMPCP credit} = \text{REG}_t \times \eta_t \times \beta_t^M \times \text{RMPCP}_t$$

η_t	Performance score at time t (%)
β_t^M	Mileage ratio at time t
RMPCP_t	Regulation Market Performance Clearing Price (\$/MWh)
RMCCP_t	Regulation Market Capability Clearing Price (\$/MWh)

Results - Models

- Arbitrage energy storage model

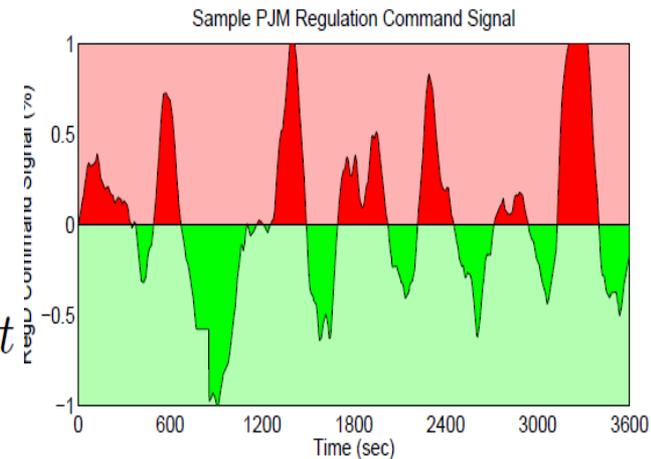
$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D$$

- Arbitrage plus regulation model

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_t^{RD} q_t^{REG} - \gamma_t^{RU} q_t^{REG}$$

- Arbitrage + regulation cost function

$$\max \sum_{t=1}^T [(P_t - C_d) q_t^D - (P_t + C_r) q_t^R + q_t^{REG} \eta_t (\beta_t^M RMPCP_t + RMCCP_t)] e^{-rt}$$



Results, 20 MW/5 MWh System

ARBITRAGE AND REGULATION OPTIMIZATION RESULTS
USING PERFECT KNOWLEDGE, JUNE 2014-MAY 2015.
COMPARISON OF REVENUE STREAMS.

ARBITRAGE AND REGULATION OPTIMIZATION RESULTS USING PERFECT
KNOWLEDGE, JUNE 2014-MAY 2015.

Month	% q^R	% q^D	% q^{REG}	Revenue
06/14	0.65	0.41	98.67	\$487,185.94
07/14	1.22	0.38	98.06	\$484,494.90
08/14	1.20	0.38	98.06	\$354,411.61
09/14	1.23	0.52	97.73	\$401,076.97
10/14	1.30	0.38	97.85	\$535,293.84
11/14	1.71	0.58	96.43	\$431,106.41
12/14	1.07	0.50	96.92	\$341,281.46
01/15	0.80	1.10	97.34	\$443,436.10
02/15	1.03	1.37	96.59	\$998,392.65
03/15	0.87	0.71	98.41	\$723,692.29
04/15	0.90	0.20	98.76	\$527,436.11
05/15	1.02	0.37	98.62	\$666,290.70
			Total	\$6,394,098.97

Month	RMCCP Credit	RMPCP Credit	Arbitrage Credit	Total Revenue
06/14	\$356,412.73	\$130,286.06	\$487.16	\$487,185.94
07/14	\$351,131.53	\$135,123.18	-\$1,759.82	\$484,494.90
08/14	\$231,708.06	\$124,760.87	-\$2,057.32	\$354,411.61
09/14	\$280,496.49	\$121,979.31	-\$1,398.84	\$401,076.97
10/14	\$389,520.38	\$148,445.40	-\$2,671.94	\$535,293.84
11/14	\$315,773.83	\$117,698.79	-\$2,366.21	\$431,106.41
12/14	\$250,525.71	\$92,077.48	-\$1,321.73	\$341,281.46
01/15	\$335,093.93	\$102,707.75	\$5,634.43	\$443,436.10
02/15	\$837,537.28	\$141,229.67	\$19,625.70	\$998,392.65
03/15	\$561,451.79	\$160,354.43	\$1,886.07	\$723,692.29
04/15	\$373,388.33	\$155,942.07	-\$1,894.29	\$527,436.11
05/15	\$537,115.47	\$129,786.70	-\$611.47	\$666,290.70
Total	\$4,820,155.53 75.38%	\$1,560,391.71 24.40%	\$13,551.74 0.21%	\$6,394,098.97 100%

Conclusions/Recommendations

- Formulated the revenue maximization problem for energy storage in PJM
- Calculated the maximum potential revenue over a 12 month period using historical market data
 - 20 MW, 5 MWh, 85 % efficiency, 2 %/hour losses
 - Frequency regulation yields more revenue than arbitrage
- Evaluated a heuristic trading algorithm that does not require perfect foresight, captured 92.5 % of the maximum potential revenue
- Plan to look at other market areas
- In the process of posting Pyomo/Python code on SNL website