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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:

$$\text{RMCCP credit} = REG_t \times \eta_t \times RMCCP_t$$

$$\text{RMPCP credit} = REG_t \times \eta_t \times \beta_t^M \times RMPCP_t$$

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

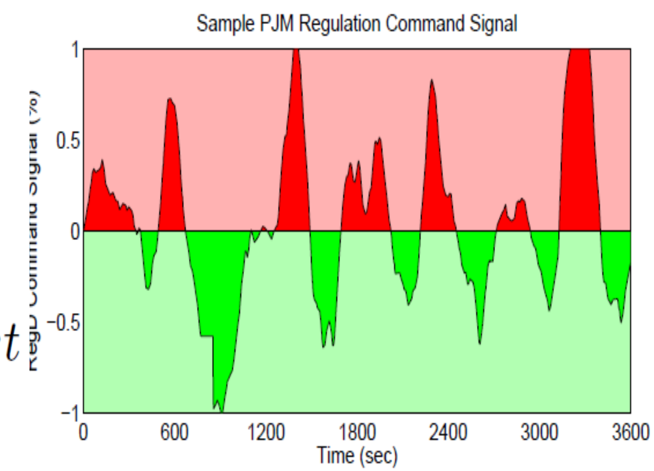
$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D$$

- 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

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ARBITRAGE AND REGULATION OPTIMIZATION RESULTS USING PERFEC 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

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

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