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Estimating Potential Revenue from Electrical Energy Storage in PJM

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Objectives:

- Formulate the revenue maximization problem for energy storage in PJM
- Analyze historical data for a representative system
- Identify the strategy that maximizes potential revenue
- Present results for a heuristic trading strategy that does not require perfect foresight

PJM Regulation Market:

Payments for capacity and mileage

RMCCP Regulation Market Capability Clearing Price

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

RMPCP Regulation Market Performance Clearing Price

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

where:

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)
REG_t	hourly integrated regulation

Energy Storage Model:

Arbitrage

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D$$
$$0 \leq S_t \leq \bar{S}, \ \forall t \in T$$
$$0 \leq q_t^R \leq \bar{q}^R, \ \forall t \in T$$
$$0 \leq q_t^D \leq \bar{q}^D, \ \forall t \in T$$

Arbitrage and Frequency Regulation

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_t^{RD} q_t^{REG} - \gamma_t^{RU} q_t^{REG}$$
$$0 \leq S_t \leq \bar{S}, \ \forall t \in T$$
$$0 \leq q_t^R + q_t^{REG} \leq \bar{q}^R, \ \forall t \in T$$
$$0 \leq q_t^D + q_t^{REG} \leq \bar{q}^D, \ \forall t \in T$$

Cost Function:

P_t	LMP for energy at time t $/MWh)
C_d	Cost for discharging ($/MWh)
C_r	Cost for recharging ($/MWh)
q_t^D	Energy discharged at time t (MWh)
q_t^R	Energy charged at time t (MWh)
q_t^{REG}	Regulation capability at time t (MWh)
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)
e^{-rt}	Discounting term (time value of money)

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

Results for 2014/2015 Market Data:

ENERGY STORAGE SYSTEM PARAMETERS.

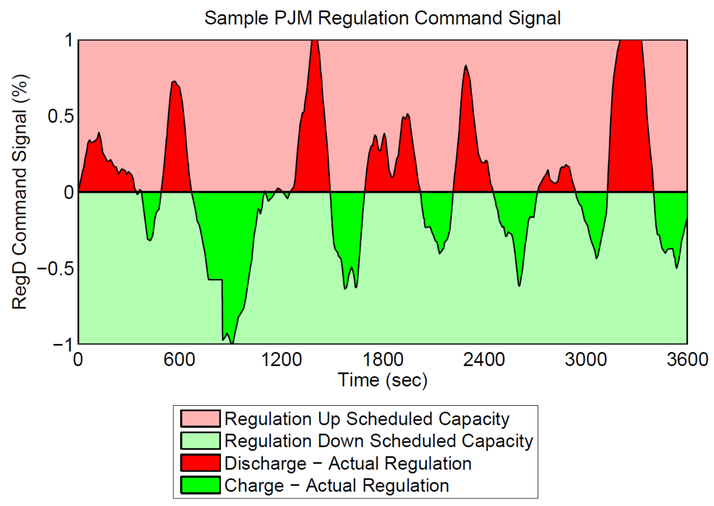
Parameter	Value
$\bar{q}^D$	20 MWh
$\bar{q}^R$	20 MWh
$\bar{S}$	5 MWh
γ_s	0.98
γ_c	0.85
η_t	0.95

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

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:

- For the year analyzed, the optimal policy to maximize revenue is to participate in the frequency regulation market
- A simple heuristic trading algorithm was able to capture 92.5% of the maximum potential revenue
- With gross revenue potential around $6M/year, various energy storage technologies start to offer a reasonable payback period

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