Potential Revenue from Electrical Energy Storage in ERCOT: The Impact of Location and Recent Trends

R. H. Byrne and C.A. Silva-Monroy

Sandia National Laboratories, Albuquerque, NM 87185 USA

RESEARCH GOALS

- Investigate the potential revenue for electrical energy storage in ERCOT
- Employ historical market data from 2011, 2012, and 2013
- Evaluate arbitrage as well as arbitrage and frequency regulation
- Assume "perfect knowledge"
- Analyze all load zones in ERCOT

TABLE I
STORAGE PARAMETERS

Symbol	Storage Parameter
τ	Time period length (e.g. one hour).
T	Number of time periods in optimization.
$\bar{q}^D$	Maximum energy sold in a single period (MWh).
$\bar{q}^R$	Maximum energy bought in a single period (MWh).
$\bar{S}$	Maximum energy storage capacity (MWh).
γ_S	Storage efficiency over one period (%).
γ_C	Conversion efficiency (%).

Energy storage model – arbitrage only

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

Constraints
$$0 \leq S_t \leq \bar{S}, \; \forall t \in T$$
$$0 \leq q_t^R \leq \bar{q}^R, \; \forall t \in T$$
$$0 \leq q_t^D \leq \bar{q}^D, \; \forall t \in T$$

Energy storage model – arbitrage and regulation

$$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D + \gamma_c \gamma_{rd} q_t^{RD} - \gamma_{ru} q_t^{RU}$$

Constraints
$$0 \leq S_t \leq \bar{S}, \; \forall t \in T$$
$$0 \leq q_t^R + q_t^{RD} \leq \bar{q}^R, \; \forall t \in T$$
$$0 \leq q_t^D + q_t^{RU} \leq \bar{q}^D, \; \forall t \in T$$
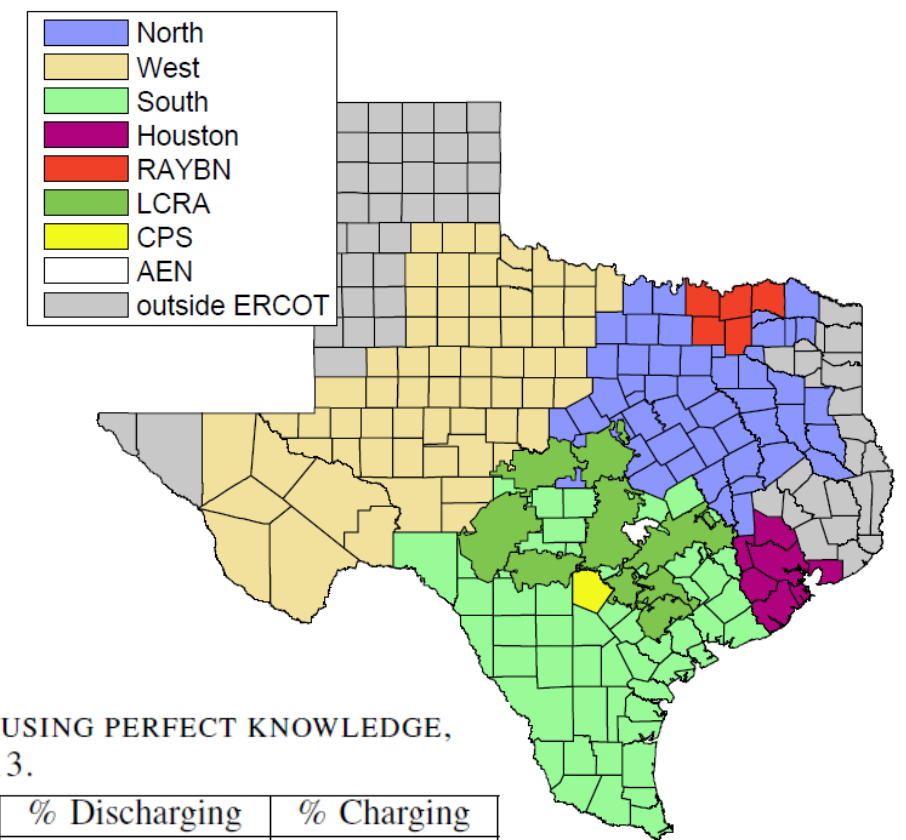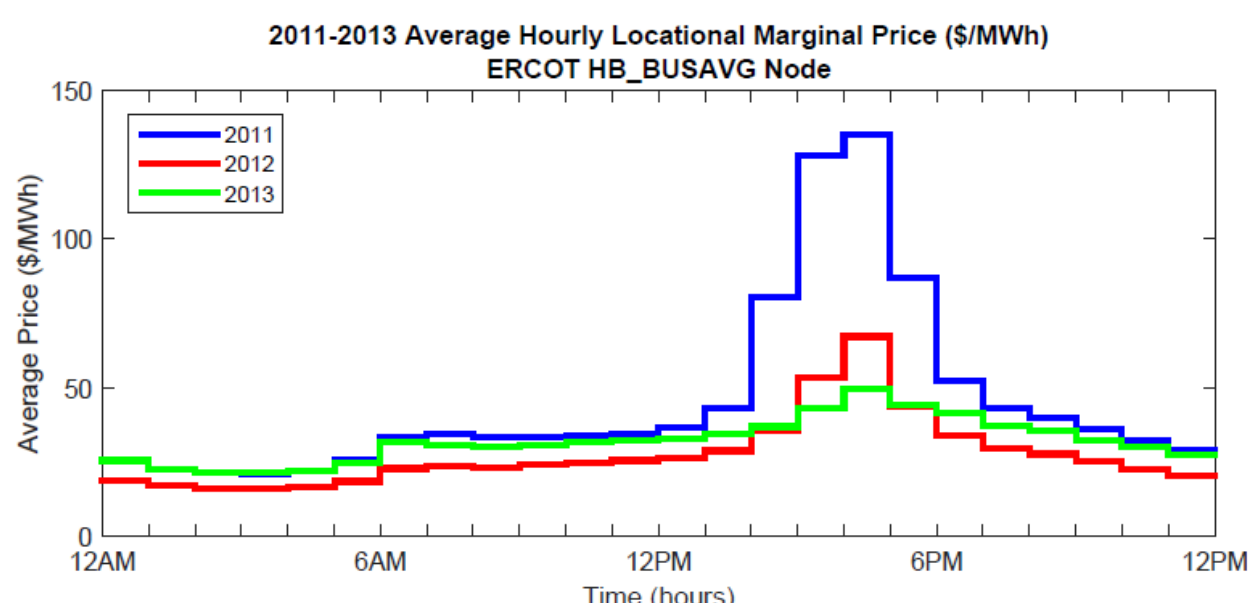
Objective function - arbitrage

$$\max \sum_{t=1}^{T} \left[(P_t - C_d) q_t^D - (P_t + C_r) q_t^R \right] e^{-rt}$$

Objective function – arbitrage and regulation

$$\max \sum_{t=1}^{T} [(P_t - C_d) q_t^D + (P_t^{RU} + \gamma_{ru}(P_t - C_d)) q_t^{RU} + (P_t^{RD} - \gamma_{rd}(P_t + C_r)) q_t^{RD} - (P_t + C_r) q_t^R] e^{-rt}$$

TABLE III
ENERGY STORAGE SYSTEM PARAMETERS.

Parameter	Value
$\bar{q}^D$	8 MWh
$\bar{q}^R$	8 MWh
$\bar{S}$	32 MWh
γ_S	1.0
γ_C	0.8
γ_{ru}	0.5
γ_{rd}	0.5

2011-2013 Average Hourly Locational Marginal Price ($/MWh) ERCOT HB_BUSAVG Node

ARBITRAGE OPTIMIZATION RESULTS USING PERFECT KNOWLEDGE, 2011-2013.

Load Zone	Year	Revenue	% Discharging	% Charging
North	2011	$1,063,599.54	18.90%	23.62%
	2012	$382,066.41	18.00%	22.50%
	2013	$254,605.18	18.81%	23.52%
South	2011	$1,076,180.49	18.78%	23.47%
	2012	$426,627.76	17.69%	22.11%
	2013	$289,562.01	18.62%	23.28%
West	2011	$1,182,502.88	20.00%	25.00%
	2012	$733,646.82	17.95%	22.44%
	2013	$517,344.45	18.49%	23.11%
Houston	2011	$1,063,385.41	18.84%	23.56%
	2012	$381,959.28	17.91%	22.38%
	2013	$280,054.47	18.78%	23.48%
RAYBN	2011	$1,057,443.51	18.91%	23.63%
	2012	$373,162.63	17.96%	22.45%
	2013	$250,356.83	18.78%	23.48%
LCRA	2011	$1,055,417.81	18.89%	23.62%
	2012	$449,793.75	17.97%	22.46%
	2013	$276,481.46	18.84%	23.55%
CPS	2011	$1,061,561.72	18.82%	23.53%
	2012	$391,876.86	17.99%	22.48%
	2013	$287,515.07	18.89%	23.62%
AEN	2011	$1,043,716.52	18.76%	23.45%
	2012	$368,224.91	17.92%	22.40%
	2013	$289,537.70	18.84%	23.56%

ARBITRAGE AND REGULATION OPTIMIZATION RESULTS USING PERFECT KNOWLEDGE, 2011-2013.

Year	Revenue	% q^D	% q^R	% q^{RU}	% q^{RD}
North Load Zone					
2011	$2,370,777.09	0.11%	0.87%	69.63%	85.62%
2012	$933,260.45	0.11%	0.83%	63.59%	78.12%
2013	$843,543.43	0.10%	1.38%	62.77%	75.98%
South Load Zone					
2011	$2,369,779.67	0.26%	0.99%	69.32%	85.36%
2012	$955,300.23	0.44%	0.94%	61.95%	76.67%
2013	$858,726.34	0.10%	1.35%	61.23%	74.11%
West Load Zone					
2011	$2,438,594.42	0.010%	2.23%	69.01%	82.16%
2012	$1,163,443.68	1.86%	2.57%	51.25%	63.61%
2013	$1,007,779.09	0.98%	2.57%	54.16%	65.03%
Houston Load Zone					
2011	$2,363,966.11	0.15%	0.85%	69.31%	85.37%
2012	$931,141.19	0.089%	0.78%	63.53%	78.09%
2013	$854,588.16	0.089%	1.30%	61.09%	73.99%
RAYBN Load Zone					
2011	$2,367,663.02	0.11%	0.84%	69.71%	85.78%
2012	$928,295.59	0.11%	0.83%	63.73%	78.31%
2013	$840,455.24	0.10%	1.44%	62.92%	76.02%
LCRA Load Zone					
2011	$2,362,665.58	0.17%	0.88%	69.24%	85.23%
2012	$982,249.28	0.61%	0.81%	61.34%	76.59%
2013	$853,824.74	0.10%	1.23%	61.40%	74.55%
CPS Load Zone					
2011	$2,359,793.64	0.14%	0.87%	69.32%	85.31%
2012	$938,393.86	0.23%	0.84%	63.38%	78.14%
2013	$856,761.94	0.17%	1.43%	60.95%	73.77%
AEN Load Zone					
2011	$2,355,535.66	0.14%	0.85%	69.73%	85.86%
2012	$925,236.23	0.10%	0.87%	64.26%	78.86%
2013	$862,277.62	0.12%	1.26%	60.38%	73.28%

CONCLUSION

- The increased revenue in 2011 was likely an outlier due to an ice storm in February and a heat wave in August
- Frequency regulation provides more revenue than arbitrage
- Since the dominant revenue source is frequency regulation – location is not important unless other services are added, e.g., T&D deferral