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

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2015 DOE/OE Energy Storage Program Peer Review meeting
September 24, 2015

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Project Goals

- Quantify the potential revenue from electrical energy storage in ERCOT
- Identify the impact of location
  - Analyzed all 8 load zones
- Identify trends
  - Analyzed 2011, 2012, and 2013 data
- Potential revenue streams:
  - Arbitrage
  - Frequency regulation

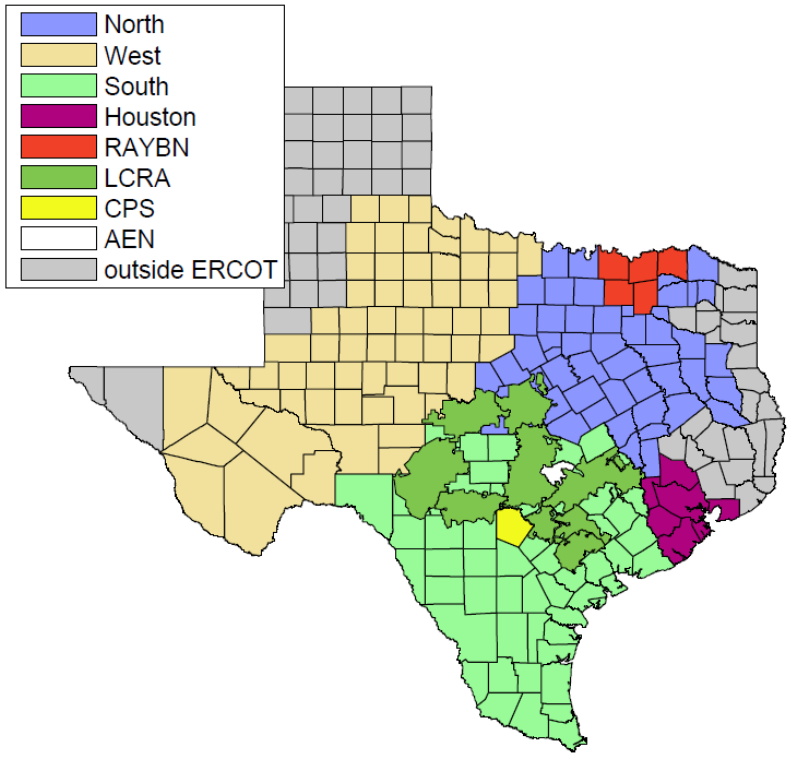


Fig. 1. Illustration of ERCOT load zones.

ACKNOWLEDGMENT: the authors would like to thank Dr. Imre Gyuk and his colleagues at the Energy Storage Program at the U.S. Department of Energy for funding this research.

Methodology

- Formulated the problem as a Linear Program (LP) optimization
  - Solved in MATLAB and Pyomo
  - Working to release the Pyomo code
  - Day ahead market data from ERCOT web site
  - Looked at the revenue opportunity (no cost data)
  - Optimization codes applicable to any market data
- Optimization objective function
  - Arbitrage

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

  - Arbitrage and frequency regulation

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

Methodology

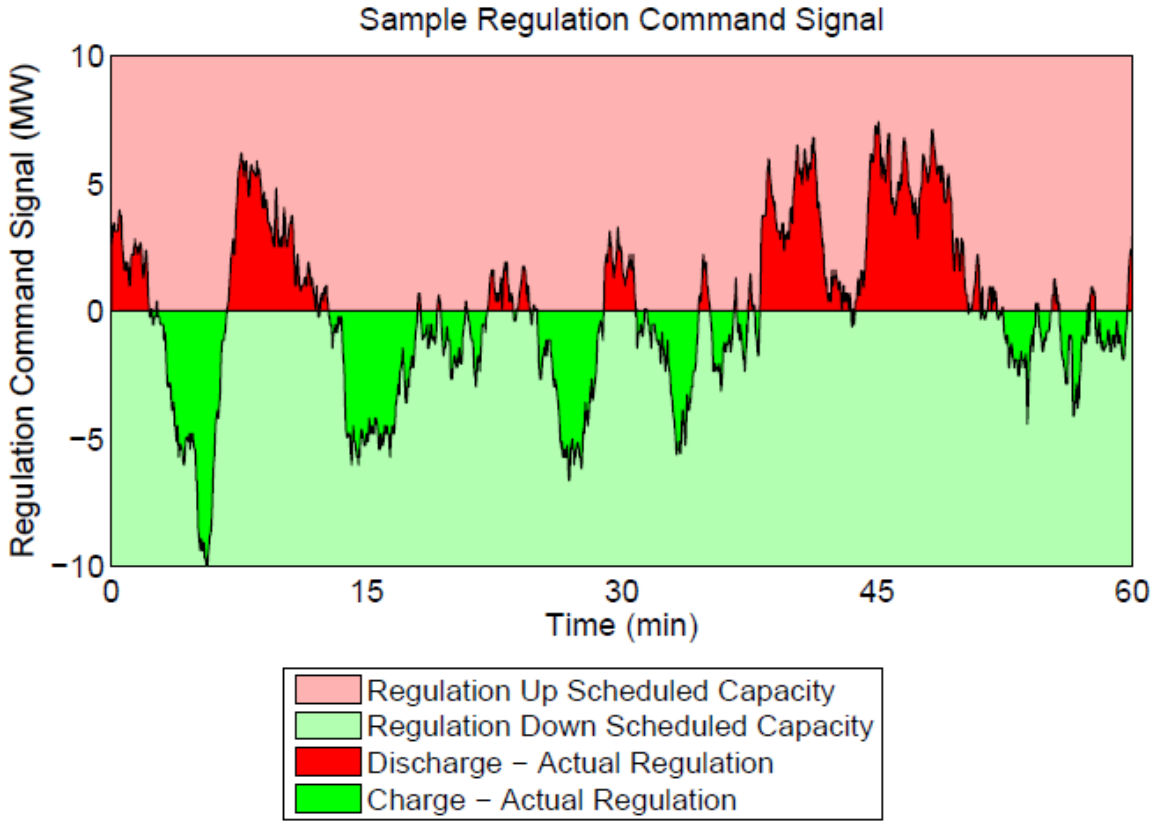
- Energy storage model
  - Arbitrage $$S_t = \gamma_s S_{t-1} + \gamma_c q_t^R - q_t^D$$
  - Arbitrage and frequency regulation

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

q_t^R	charge quantity in time period t (MWh)
q_t^D	discharge quantity in time period t (MWh)
q_t^{RU}	quantity bid into the regulation up market (MWh)
q_t^{RD}	quantity bid into the regulation down market (MWh)
γ_{RU}	fraction of regulation up bid that is accepted (%)
γ_{RD}	fraction of regulation down bid that is accepted (%)
γ_S	storage efficiency over one period (%)
γ_C	conversion efficiency (%)

Methodology

- Handling frequency regulation
  - Make an assumption about the average fraction that is called
  - Sensitivity analysis shows that the results are not sensitive to this parameter



Methodology

- Energy storage system constraints
  - Arbitrage

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

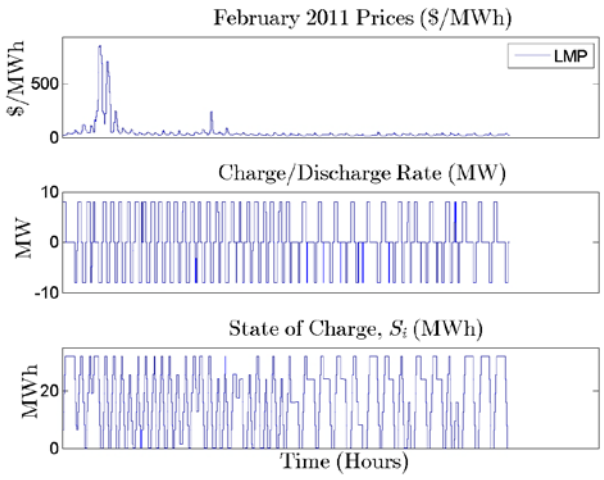
  - Arbitrage and frequency regulation

$$0 \leq S_t \leq \bar{S}, \ \forall t \in T$$
$$0 \leq q_t^R + q_t^{RD} \leq \bar{q}^R, \ \forall t \in T$$
$$0 \leq q_t^D + q_t^{RU} \leq \bar{q}^D, \ \forall t \in T$$

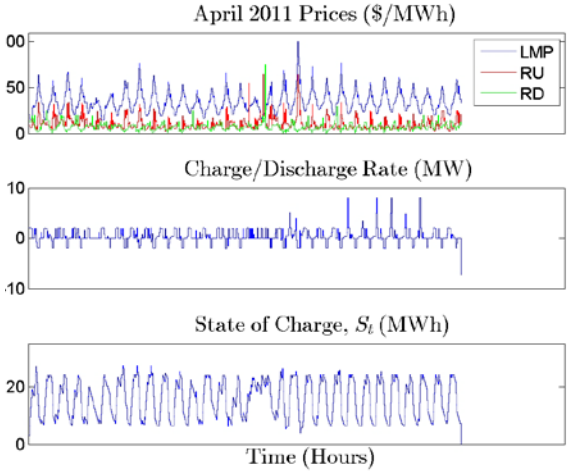
  - Note: set up constraints so that you always have the charge available to provide frequency regulation (even though a fraction is modeled as called)

System Model

- Assumed perfect knowledge
  - Can recoup 85-90% of arbitrage maximum revenue with simpler algorithms
  - Can recoup 90-95% of arbitrage/frequency regulation maximum revenue with simpler algorithms
- Did not consider arbitrage between day ahead and real-time market



Arbitrage



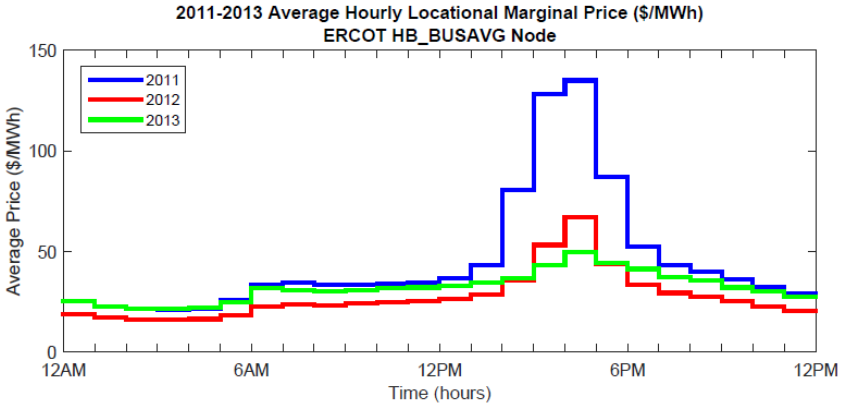
Arbitrage & regulation

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

Results - Arbitrage

- 2011 had significantly more potential revenue
- Not a large difference by region, although the West Load zone had more opportunity



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%

Results – Arbitrage and Regulation

- Significantly more potential revenue in the frequency regulation market
- Once again 2011 had significantly more potential revenue
- Since there is one market for regulation, and has significantly more revenue => location not as important
- The West load zone had slightly higher revenue opportunity

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%

Summary

- Increased potential revenue in 2011 can be explained by
  - Ice storms in February
  - Record heat in August
  - 2012-2013 data probably more typical
- For arbitrage – West load zone has the highest potential revenue
- For arbitrage and regulation – the optimal policy is participate in the frequency regulation market
  - One market for regulation diminishes the impact of location on potential revenue
- Additional details:

R. H. Byrne, C. A. Silva-Monroy, "Potential Revenue from Electrical Energy Storage in ERCOT: The Impact of Location and Recent Trends", Proceedings of the IEEE PES General Meeting, Denver, July, 2015.