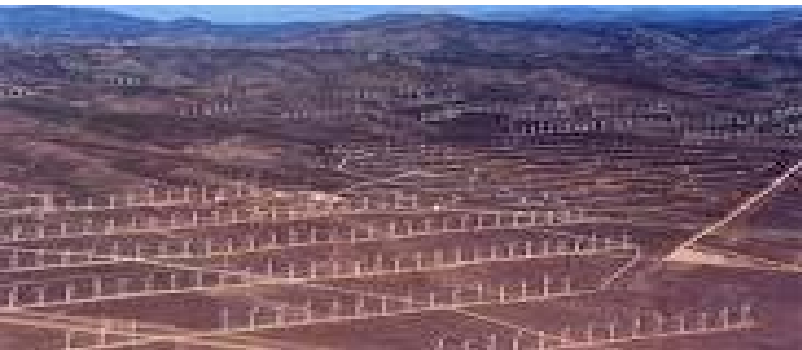


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Economics of Storage

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Economics of Storage

- Analysis of energy storage value streams is location dependent
 - Market area
 - Vertically integrated utility
- Often there is a technical performance component
 - Stability analysis
 - Transient response from a generator drop
 - Ramp rate limiting for renewable integration
- Until policy and regulations catch up, storage owners are not compensated for some potential services
 - Carbon reduction
 - Synthetic inertia
 - Voltage support



Energy Storage Revenue – Market Areas Sandia National Laboratories

- Two most common revenue streams in market areas:
 - Arbitrage (buy low, sell high)
 - Frequency regulation
- Additional revenue streams
 - Reductions in forward capacity market payments
 - Reductions in transmission service payments
 - Spinning reserve
- How do you estimate maximum potential revenue?
 - Energy storage plant model
 - Historical market data
 - Assume perfect foresight (e.g., know the future)
 - Test strategies that don't rely on perfect foresight



Maximizing Revenue - Market Area

- Linear Program Optimization
 - MATLAB
 - Python/Pyomo
- Typically look at the following revenue streams
 - Arbitrage
 - Arbitrage + Regulation
 - Allocate charge to avoid double counting
- Typically look at maximizing revenue
- Can incorporate cost data (if available)
 - Penalty for charge/discharge
 - Variable O&M costs
 - Modeling relationship between lifetime and charge/discharge profile is an active research area



Maximizing Revenue – Market Area

- Recent case studies:
 - CAISO [1] (included sensitivity analysis to parameters)
 - ERCOT [2,3]
 - PJM [4]
 - ISO-NE (in progress)



- [1] R. H. Byrne, and C. A. Silva-Monroy, *Estimating the Maximum Potential Revenue for Grid Connected Electricity Storage: Arbitrage and Regulation*, SAND2012-3863, Sandia National Laboratories, Albuquerque, NM 87185, 2012.
- [2] R. H. Byrne, and C. A. Silva-Monroy, "Potential Revenue from Electrical Energy Storage in the Electricity Reliability Council of Texas (ERCOT)," in IEEE Power and Energy Society (PES) General Meeting, Washington, DC, 2014.
- [3] R. H. Byrne and C. A. Silva-Monroy, "Potential revenue from electrical energy storage in ERCOT: The impact of location and recent trends," in Proceedings of the 2015 IEEE Power and Energy Society (PES) General Meeting, Denver, CO, July 2015, pp. 1-5.
- [4] R. H. Byrne, R. Concepcion, and C. A. Silva-Monroy, "Estimating potential revenue from electrical energy storage in PJM," Proceedings of the 2016 IEEE Power and Energy Society (PES) General Meeting, Boston, MA, July 2016, pp.1-5.

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Market Area Results

- CAISO
 - Frequency regulation is the optimum policy
- ERCOT
 - Frequency regulation is the optimum policy
 - Location does not matter
- PJM
 - Frequency regulation is the optimum policy
- ISO NE
 - Frequency regulation
 - Forward Capacity Market (FCM) payment reduction
 - Regional Network Services (RNS) payment reduction



Vertically Integrated Utilities

- Cost savings are typically the primary benefit of energy storage
 - Production cost modelling analysis
 - Improved operation of traditional generators
 - Reduced curtailment of renewables
 - Reduced reserve requirements (e.g., turn off must-run generators)
 - Transmission and Distribution (T&D) deferral
 - Can be a very large savings
 - Very location specific
 - Often there are competing alternatives (e.g., demand response, conservation, etc.)
 - Distribution level
 - Voltage support
 - Renewable integration
 - Grid resiliency

Vertically Integrated Utilities

- Recent case studies:
 - Nevada Energy [1]
 - Southern Company [2]
 - Maui Electric Company [3]
 - Hawaiian Electric Company



- [1] J. F. Ellison, D. Bhatnagar, N. Saaman *et al.*, *NV Energy Electricity Storage Valuation*, SAND2013-4902, Sandia National Laboratories, Albuquerque, NM 87185, 2013.
- [2] J. Ellison, D. Bhatnagar, C. Black *et al.*, *Southern Company Energy Storage Study: A Study for the DOE Energy Storage Systems Program*, SAND2013-2251, Sandia National Laboratories, Albuquerque, NM 87185, 2013.
- [3] J. Ellison, D. Bhatnagar, and B. Karlson, *Maui Energy Storage Study*, SAND2012-10314, Albuquerque, NM 87185, 2012.

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Economics of Energy Storage

- Different approaches for estimating value streams
 - Market areas
 - Vertically integrated utilities
- Analysis is typically very location dependent
 - Technical requirements
 - Policy & regulations
- Once applications and value streams have been modelled and quantified – selecting the appropriate technology is the next step
 - Return-on-investment can vary significantly by energy storage technology
- The efficacy of algorithms to operate the system should be evaluated – potential impact on revenue / grid benefits