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Economics of Storage

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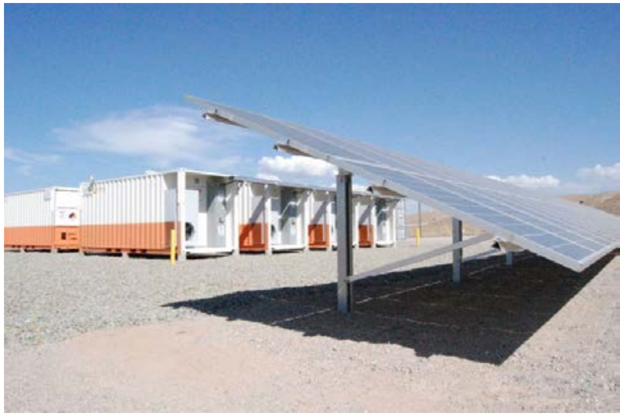
U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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



J. Eyer and G. Corey, “Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide”, Sandia National Laboratories, SAND2010-0815, February 2010.

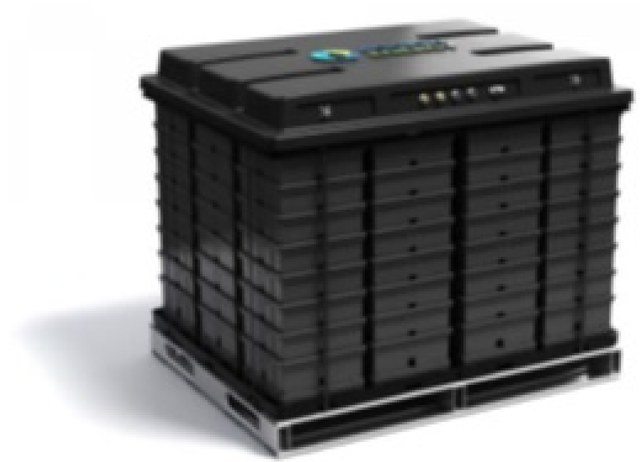
Energy Storage Revenue – Market Areas

- 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.

Reports available at: http://www.sandia.gov/ess/

Market Area Results

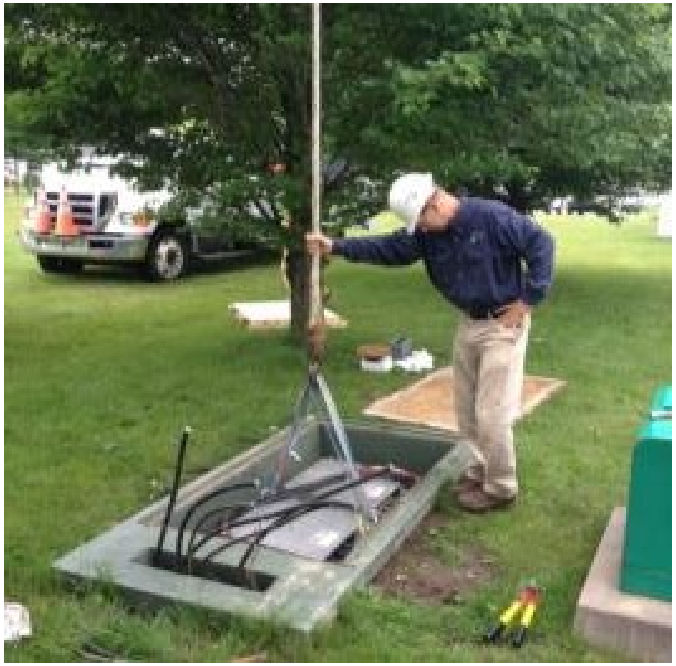
- CAISO
  - Frequency regulation is the optimum policy
- ERCOT
  - Frequency regulation is the optimum policy
  - Location does not matter
- PJM
  - Frequency regulation is the optimum policy
- ISO NE
  - Frequency regulation
  - Forward Capacity Market (FCM) payment reduction
  - Regional Network Services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

Reports available at: http://www.sandia.gov/ess/

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