Models for Evaluation and Optimization of Grid-Scale Energy Storage

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Project Objectives

- Model development for **evaluation** and **optimization** of grid-scale **energy storage systems (ESS)**
- **Siting** and **sizing** of ESS for maximizing **economic benefits**, **stability**, and **reliability** improvement of the grid
- Developing and integrating **degradation models** of ESS in the optimization framework for more realistic economic evaluation

Degradation Cost

- New cost model—both *energy throughput* and *cycle count*
- Incorporated into the optimization framework as an *operational expense*
- **Results:**
  - — neglecting degradation cost leads to *overestimation of lifetime revenue*
  - — considering degradation cost *prolongs the lifetime of the battery*

Battery Size	W. Deg. Cost		W/o. Deg. Cost	
	Revenue ($)	Lifetime (yr.)	Revenue ($)	Lifetime (yr.)
10 MW, 5 MWh	8,116,541	6	10,492,202	5
10 MW, 10 MWh	11,062,330	8	13,865,585	6
10 MW, 20 MWh	13,139,466	10	17,629,318	8

Project Team

- **Sandia National Laboratories**: R.H. Byrne, Babu Chalamala, Tu Nguyen and Ricky Concepcion
- **Michigan State University**: Joydeep Mitra (PI) and Atri Bera

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Publications

1. A. Bera, B. Chalamala, R.H. Byrne, and J. Mitra, "**Sizing of Energy Storage for Grid Frequency Stability**", in *IEEE Transactions on Power Systems*. (Under Review)
2. A. Bera, S. Almasabi, Y. Tian, B. Chalamala, R.H. Byrne, T.A. Nguyen, and J. Mitra "**Maximizing the Investment Returns of a Grid-connected Battery considering Degradation Cost**," in *IET Generation, Transmission & Distribution (2020)*.
3. A. Bera, S. Almasabi, J. Mitra, B. Chalamala and R.H. Byrne, "**Spatiotemporal Optimization of Grid-Connected Energy Storage to Maximize Economic Benefits**," at the *2019 IEEE Industry Applications Society Annual Meeting*.
4. A. Bera, N. Nguyen and J. Mitra, "**Lifetime Revenue from Energy Storage considering Battery Degradation**," at the *2019 North American Power Symposium (NAPS)*.
5. Y. Tian, A. Bera, J. Mitra, B. Chalamala and R.H. Byrne, "**Effects of Operating Strategies on the Longevity of Li-ion Battery Energy Storage Systems**," at the *2018 IEEE Industry Applications Society Annual Meeting*.

Sizing of Energy Storage for Grid Frequency Stability[1]

- Renewable energy resources (RERs) possess little *rotational kinetic energy*—challenge for **grid frequency stability**
- ESS can compensate with **virtual inertia**
- Analytical approach—**sizing ESS** for virtual inertia support
- **Estimation of expected inertia** of system considering *generator outages* and replacement of *conventional generation with RER*
- **Probability of synchronization** of conventional units considered
- *Maximum frequency deviation* limit used to determine minimum inertia required by system

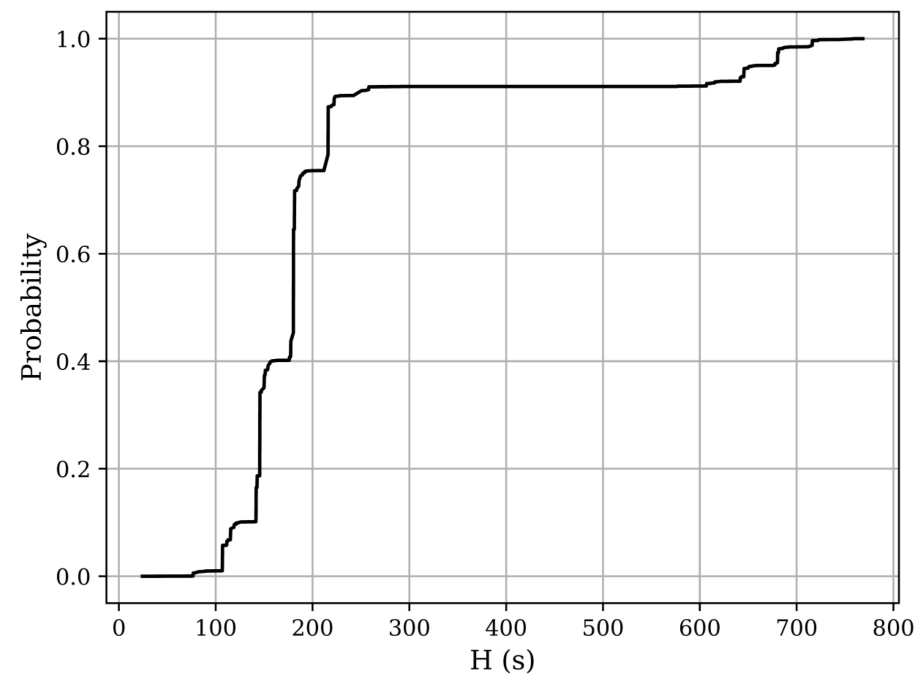

Fig. Probability distribution of system inertia of IEEE 39-bus test system

Case	Freq. Dev. Limit (Hz)	Expected Inertia (s)	P_{ESS} (MW)
No RER	0.085	580	257
	0.09		66
	0.095		N/A
8% wind penetration	0.085	579	347
	0.09		133
	0.095		N/A
20% wind penetration	0.085	552	538
	0.09		293
	0.095		93

Table. ESS sizes for a load disturbance of 0.1 p.u. (IEEE 39-bus Test System).

Maximizing Investment Returns of a Grid-Connected Battery[2]

- Quantification of **economic benefits** of BESS
- Comprehensive **investment planning** framework
- New **degradation cost** model for BESS in electricity markets
- **Li-ion** batteries: *high efficiency*, *high energy density*, *declining costs*
- **Applications:** *energy arbitrage* and *frequency regulation*
- **Cost-benefit analysis**—*payback period*, *return on investment (ROI)* and *net present value (NPV)*

Battery Size	Lifetime (yr.)	Revenue ($)	Mean Cycles (per year)
10 MW, 5 MWh	6	8,116,541	1829
10 MW, 10 MWh	8	11,062,330	1731
10 MW, 20 MWh	10	13,139,466	1526

Battery Size	Payback Period (yr.)	NPV ($)	ROI (%)
10 MW, 5 MWh	3.5	2,041,521	80.6
10 MW, 10 MWh	4.5	2,441,298	83.4
10 MW, 20 MWh	6.5	510,846	44.0

Project Synopsis

Proposed

- Optimization framework for evaluating the economic benefits of ESS
- Development and integration of degradation models
- Utilization of energy storage for stability and reliability improvement of the grid

Achieved

- Comprehensive investment planning framework developed for ESS—maximizes economic benefits
- New degradation cost model developed and integrated into the optimization framework
- Analytical approach developed for sizing of ESS for grid frequency stability

Under Development

- Framework for unifying economic, stability and reliability applications of ESS being developed
- All applications to be co-optimized
- Trade-off between operational cost of system and investment cost of ESS to be studied