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Elevating Grid Deployments of Storage with Advanced Analytics and Tools

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Pacific Northwest National Laboratory

DOE OE Energy Storage Peer Review

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ENERGY STORAGE PROGRAM

U.S. DEPARTMENT OF ENERGY BATTELLE

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Unlock Storage Potential with Advanced Analytics

ESS design and characteristics

- Energy storage technology, physical capability, and characteristics

Deployment Scenarios

- Vertically integrated utilities, electricity markets, distribution utilities, and large C&I customers

Use Cases and Applications

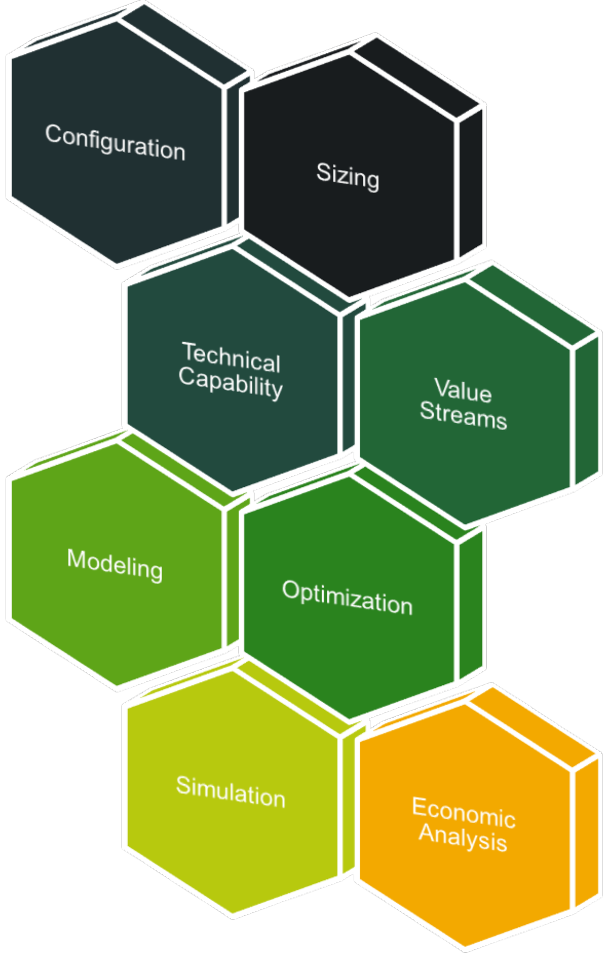
- Bulk energy, ancillary service, transmission-level, distribution-level, and end-user services

Dispatch and control strategies

- Co-optimization, rule-based control, mathematical programming, stochastic/risk-aware control, learning-based method, hybrid-control

Regions and systems

- Different generation mix, grid infrastructure, market structures/rules, distribution system capacity, and load growth rate



Inadequate capabilities for appropriately modeling and valuing energy storage have become a significant barrier to market penetration

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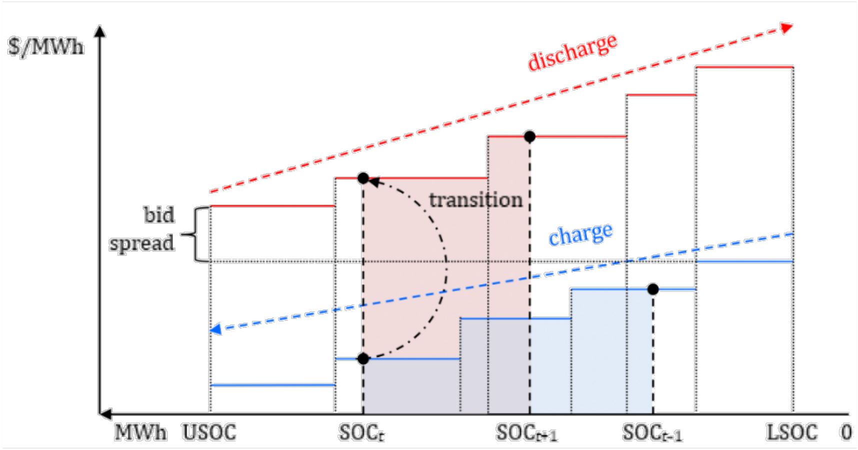
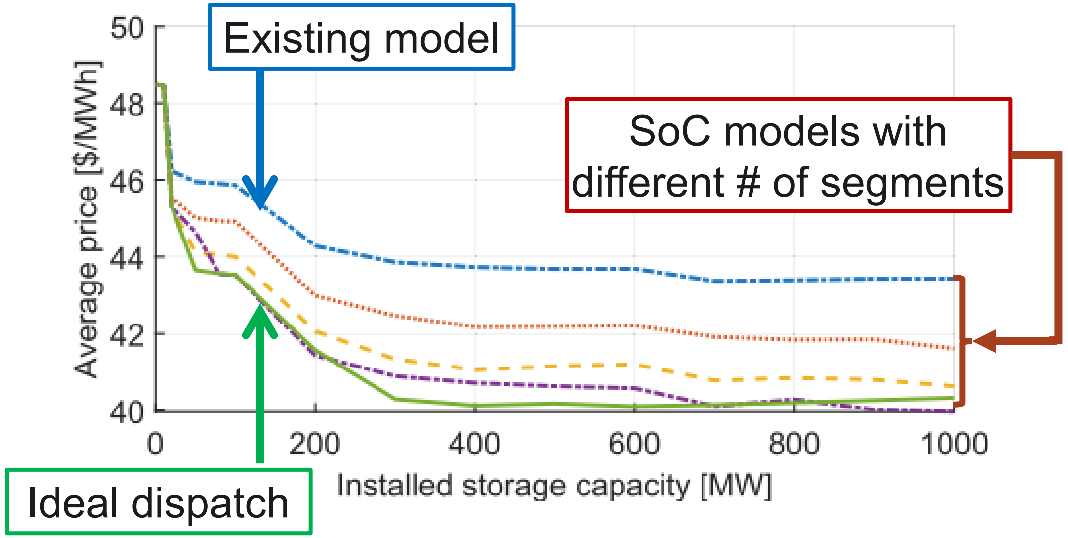
FY23 Research Activities

- Developed advanced modeling, optimization, and control methods
  - Energy storage state-of-charge market model
  - Innovative hybridization for addressing hydro plant challenges
  - Pareto efficient microgrid designs for economic and resilience equilibrium
  - Customized policy design for learning-based dispatch under uncertainties
  - Modeling and control of energy storage for enhanced system inertia
- Developed and enhanced storage valuation and control tools
  - ESET: continued maintenance and support, enhanced modeling, and database expansion
  - MSP: final adjustments, enhanced user experience, and official launch
  - ES-Control: from conceptual design to a comprehensive tool launch, including frontend/backend development, testing, and final implementation
- Provided analytical support to 10 energy storage assessment and demonstration projects

Energy Storage State-of-Charge Market Model

- Market models for energy storage resources
  - **Existing**: power-based bidding model, similar to generator resources
  - **New**: SoC-based bidding model, accounting for varying power rating, efficiency, and charge/discharge costs
- Research highlights
  - Established the theoretical foundation of the SOC-based model
  - Developed a dynamic programming algorithm for generating bids
  - Benchmarked against the existing model to quantify impacts on system costs, market prices, and storage revenue

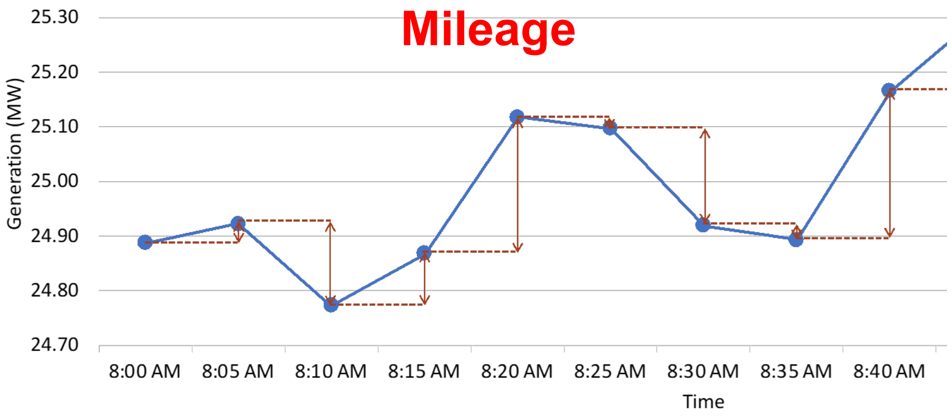


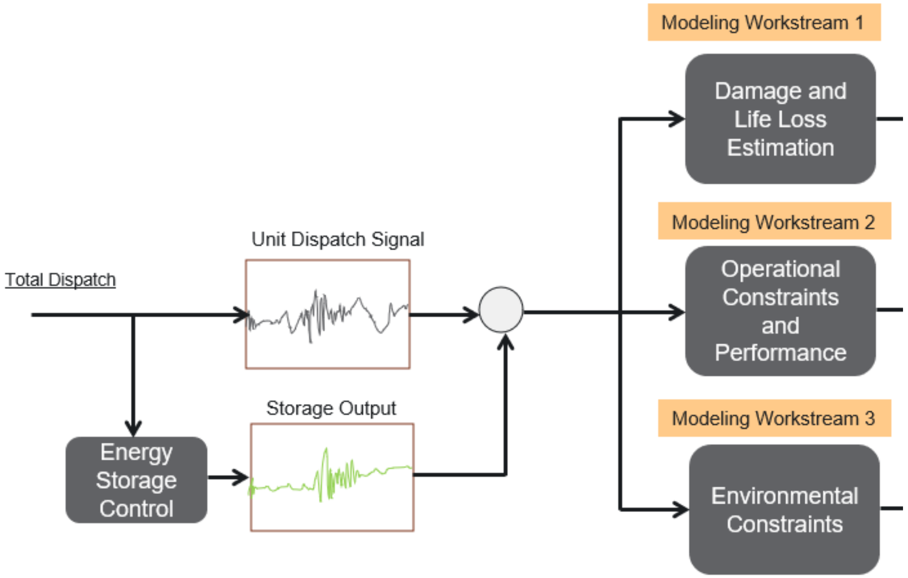


N. Zheng, X. Qin, D. Wu, G. Murtaugh, and B. Xu, "Energy Storage State-of-Charge Market Model," in *IEEE Transactions on Energy Markets, Policy and Regulation*, vol. 1, no. 1, pp. 11-22, March 2023

Innovative Hybridization for Tackling Hydro Plant Challenges

- Hydro plant challenges
  - Rising environmental constraints
  - Frequent starts and stops
  - Growing turbine mileage
  - Inefficient operation
  - Limited flexibility
- Innovative battery-hydro hybridization
  - Dynamic: Disaggregation of grid signals
    - ✓Fast for battery
    - ✓Slow for hydro
  - Steady-State: Multi-objective optimization
    - ✓Maximize economic benefits
    - ✓Minimize mileage & starts/stops
    - ✓Constraints: water levels & outflow

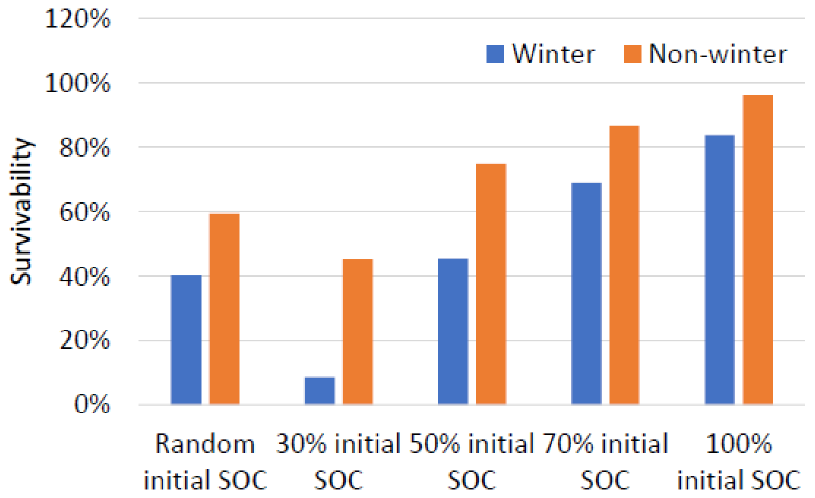


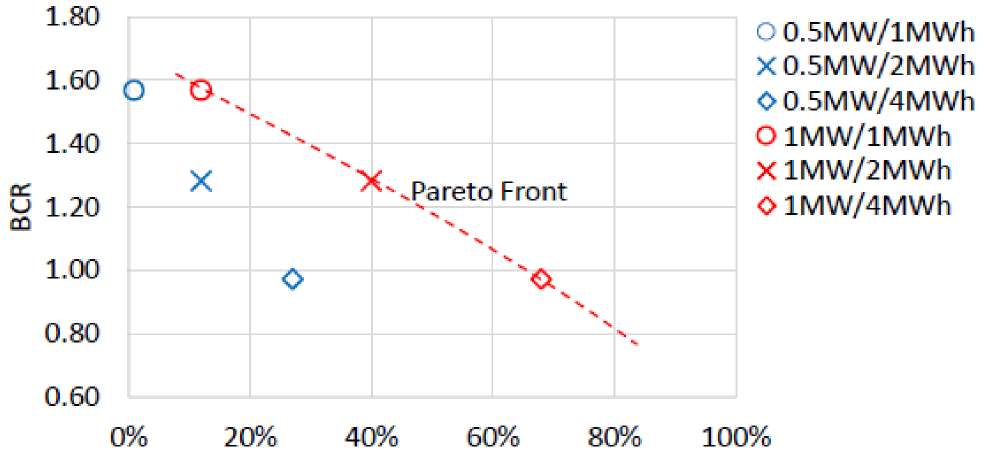


B. Bhatti, S. Hanif, J. Alam, B. Mitra, R. Kini, and D. Wu, “Using energy storage systems to extend the life of hydropower plants,” *Applied Energy*, 337, 120894, Mar. 2023.

Pareto-Efficient Microgrid Designs for Economic and Resilience Equilibrium

- Limitation of existing microgrid design
  - Resilience simplified as cost of unserved energy
  - Challenges in quantifying the economic value of resilience
  - Inability to effectively explore economic-resilience trade-off
- Innovative multi-objective framework:
  - Separate modeling of resilience and economic benefits
  - Resilience quantification via Monte Carlo simulation
  - Multi-objective optimization to identify Pareto front





Y. Zhu, X. Ma, D. Wu, and J. Do, “A multi-objective microgrid assessment and sizing framework for economic and resilience benefits,” in *Proceedings of the IEEE Power and Energy Society General Meeting*, Jul. 2023.

ESET™ Update

A suite of applications that enable various stakeholders to model, optimize, and evaluate various energy storage systems for stacked value streams

Comprehensive Models

Consistent Modeling

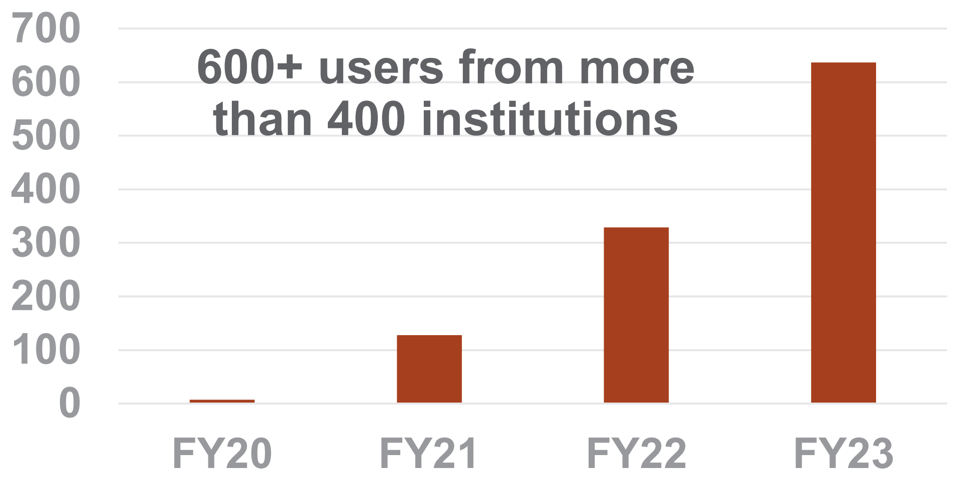
Advanced Optimization

Integrated Database

Dedicated Economic and Financial Analysis Engine

FY23 Progress

- Continued maintenance and support
- Integrated state of health modeling and simulation
- Enabled sensitivity analysis
- Expanded database and enhanced modeling

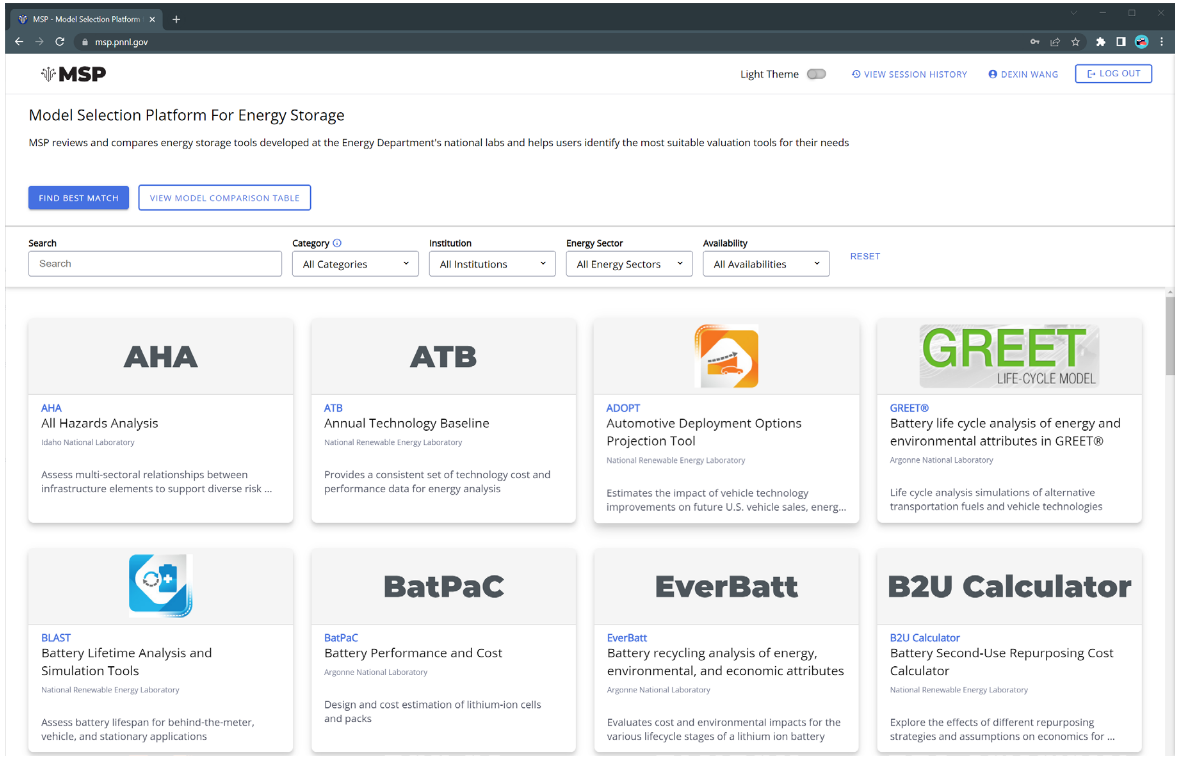


https://eset.pnnl.gov

Model Selection Platform

MSP

- Motivation
  - **Numerous options:** A variety of modeling and valuation tools exist
  - **Selection complexity:** General users may lack the time or expertise to navigate many options
- MSP: Facilitating Tool Selection
  - **Reviews and compares** 60+ DOE storage tools
  - **Scores and suggests** the best-suited tools to meet users' needs
    - ✓A hierarchical *specification discovery procedure* governs information exchange
    - ✓A *two-stage scoring engine* integrates offline setup and online calculation



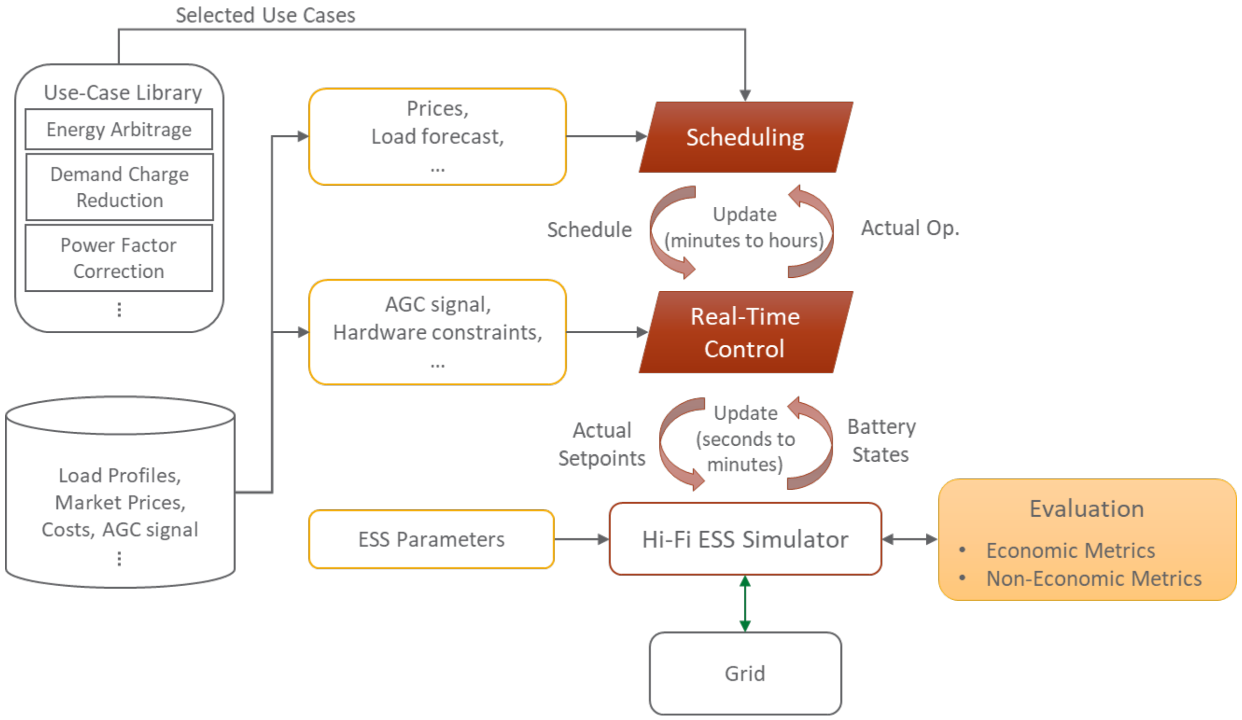
https://msp.pnnl.gov/

ES-Control Overview

Energy Storage Control

A platform for evaluation and testing of energy storage control strategies and algorithms with diversified time scales in a realistic setting, considering deployment options, use cases, and applications.

- Sandbox environment for modeling, control, simulation, and evaluation
- Representative built-in control strategies with adjustable parameters
- Open API for customized control
- Diversified energy storage models with different levels of complexity and fidelity
- Built-in database of energy storage costs, market prices, utility tariffs, etc.



https://es-control.pnnl.gov/

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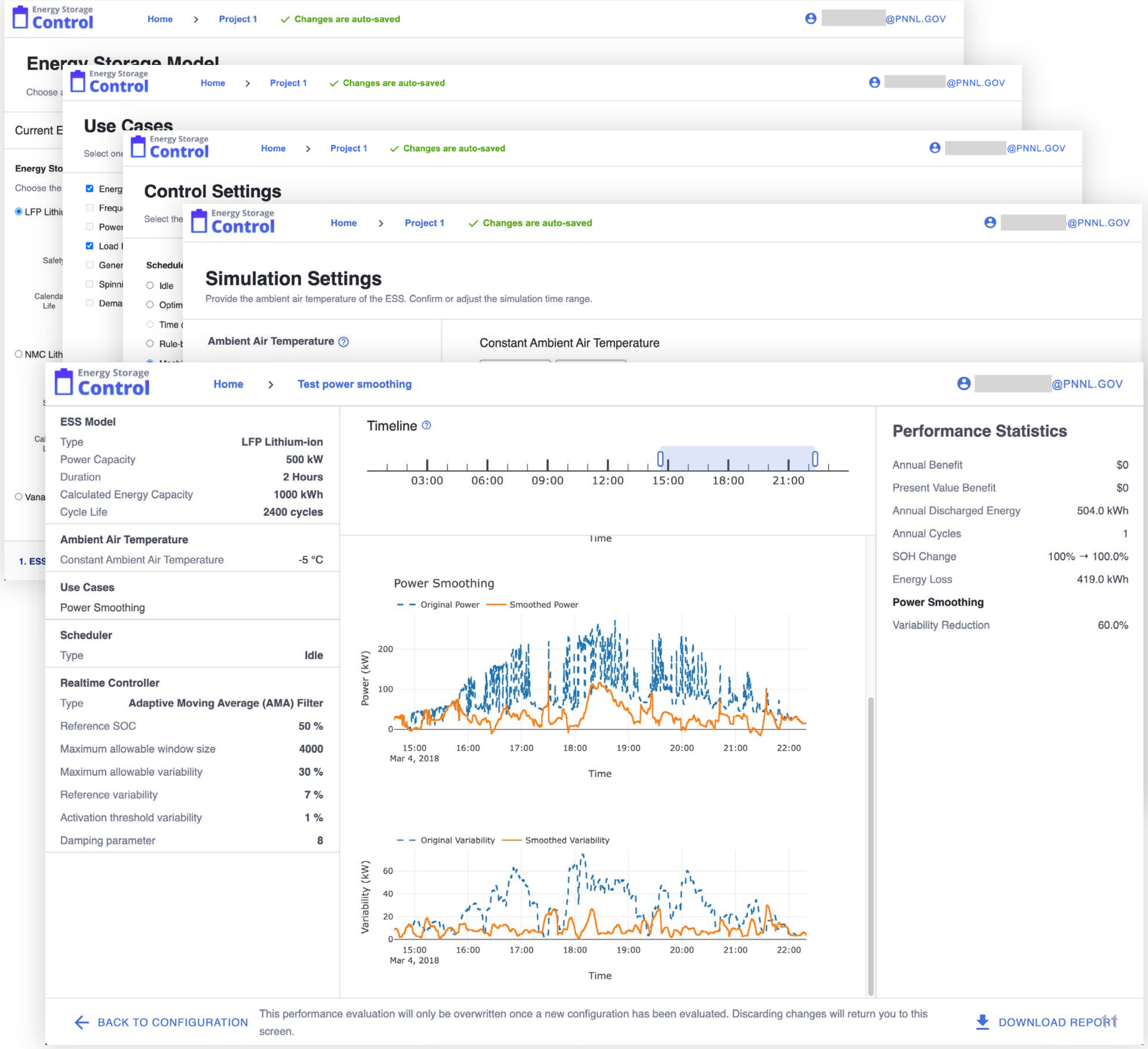
ES-Control Hosting and Interface

- A web-based application
- Microservices architecture for rapid iteration and scalability
- Off-the-shelf AWS services for fast development and industry-standard security

- Schedulers
  - Optimization
  - Reinforcement learning
  - Rule-based
- Controllers
  - Rule-based
  - PID
  - Adaptive moving average filter
  - MESA-DER (selected modes)



Look Forward

- Continue to develop advanced valuation and control capabilities
  - Optimal distribution of battery cycle life for grid services over the lifespan
  - Integration of distribution power flow and thermal/voltage constraints into siting/sizing
  - Risk-aware control to better balance economic and resilience benefits
  - Learning-based control for inter-area oscillation damping
  - Ensemble machine learning for long-duration energy storage scheduling
- Continue to enhance storage valuation and control tools
  - Provide technical support and collect feedback
  - Enhance user interface
  - Integrate additional database
  - Expand modeling, optimization, and control capabilities
- Continue to provide technical support to storage demonstration projects

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Selected FY23 Publications

1. B. A. Bhatti, S. Hanif, J. Alam, B. Mitra, R. Kini, and D. Wu, “Using energy storage systems to extend the life of hydropower plants,” *Applied Energy*, vol. 337, May 2023, 120894.
2. A. Farakhor, D. Wu, Y. Wang, and H. Fang, “A novel modular, reconfigurable battery energy storage system: design, control, and experimentation,” *IEEE Transactions on Transportation Electrification*., vol. 9, no. 2, pp. 2878–2890, Jun. 2023.
3. N. Zheng, X. Qin, D. Wu, G. Murtaugh, and B. Xu, “Energy storage state-of-charge market model,” *IEEE Transactions on Energy Markets, Policy and Regulation*, vol. 1, no. 1, pp. 11–22, Mar. 2023.
4. Fu T., H. Zhou, X. Ma, Z. Hou, and D. Wu, “Predicting Peak Day and Peak Hour of Electricity Demand with Ensemble Machine Learning,” *Frontiers in Energy Research*, vol. 10, Dec. 2022.
5. A. Das D. Wu, and Z. Ni, “Approximate dynamic programming with customized policy design for microgrid online dispatch under uncertainties,” *International Journal of Electrical Power & Energy Systems*., vol. 142, Nov. 2022, 108359
6. Y. Zhu, X. Ma, D. Wu, and J. Do, “A multi-objective microgrid assessment and sizing framework for economic and resilience benefits,” in *Proceedings of the IEEE Power and Energy Society General Meeting*, Jul. 2023.
7. R. Hu, K. Ye, H. Kim, H. Lee, N. Lu, D. Wu, and P. Rehm, “Design considerations of a coordinative demand charge mitigation strategy,” in *Proceedings of the IEEE Power and Energy Society General Meeting*, Jul. 2023.
8. X. Ma, D. Wu, and A. Crawford, “Incorporating operational uncertainties into the dispatch of an integrated solar and storage system,” in *Proceedings of the Innovative Smart Grid Technologies Conference*, Jan. 2023.
9. A. Das and D. Wu, “Optimal coordination of distributed energy resources using deep deterministic policy gradient,” in *Proceedings of Electrical Energy Storage Applications and Technologies*, Nov. 2022.
10. A. Tbaileh, M.A. Elizondo, J. Alam, C.K. Vartanian, A. Mohammednur, H. Zargaryan, and M. Avendano, “Enhanced inertial support: modeling fast frequency response controls for energy storage system inverters,” in *Proceedings of Electrical Energy Storage Applications and Technologies*, Nov. 2022.

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Mission – to ensure a resilient, reliable, and flexible electricity system through research, partnerships, facilitation, modeling and analytics, and emergency preparedness.

https://www.energy.gov/oe/energy-storage

Thank You

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https://www.pnnl.gov/energy-storage
https://eset.pnnl.gov/
https://es-control.pnnl.gov/
https://msp.pnnl.gov/