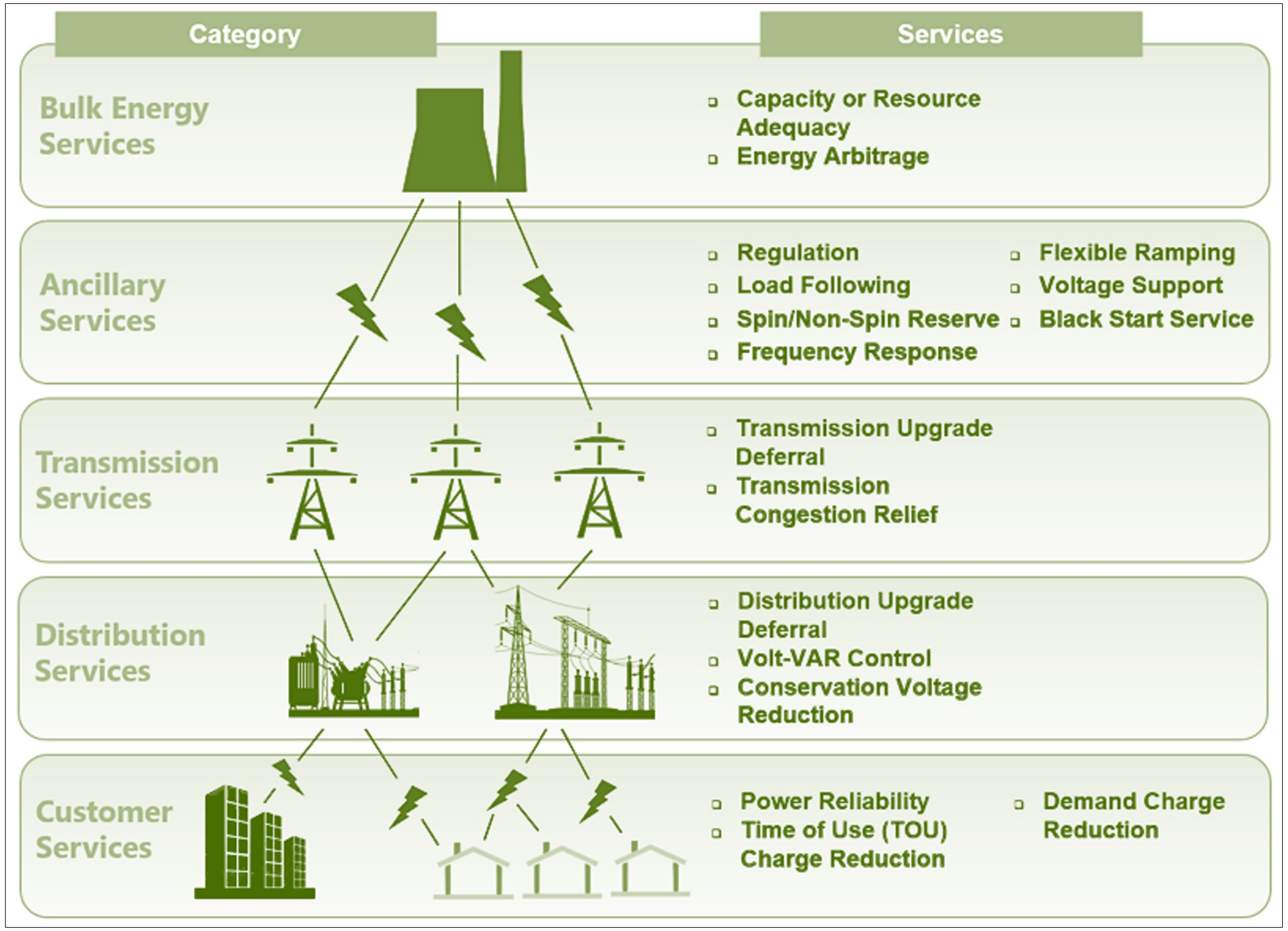
Data Analytics to Assist the Design of Storage-enabled Microgrid

Di Wu, Chief Research Engineer
Pacific Northwest National Laboratory
IEEE PES General Meeting
July 20th, 2023

Storage Can Help Solve Problems in All Parts of The Grid



PNNL Has Assessed Energy Storage and Microgrid Systems at More Than 30 Sites

- Battery Energy Storage
- Microgrids
- Hydrogen
- Building as storage
- Pumped Storage Hydro

Energy Storage and Microgrid Data Analytics

System design and characteristics

- Energy storage technology, component sizing, physical capability, and characteristics

Deployment scenarios

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

Applications and use cases

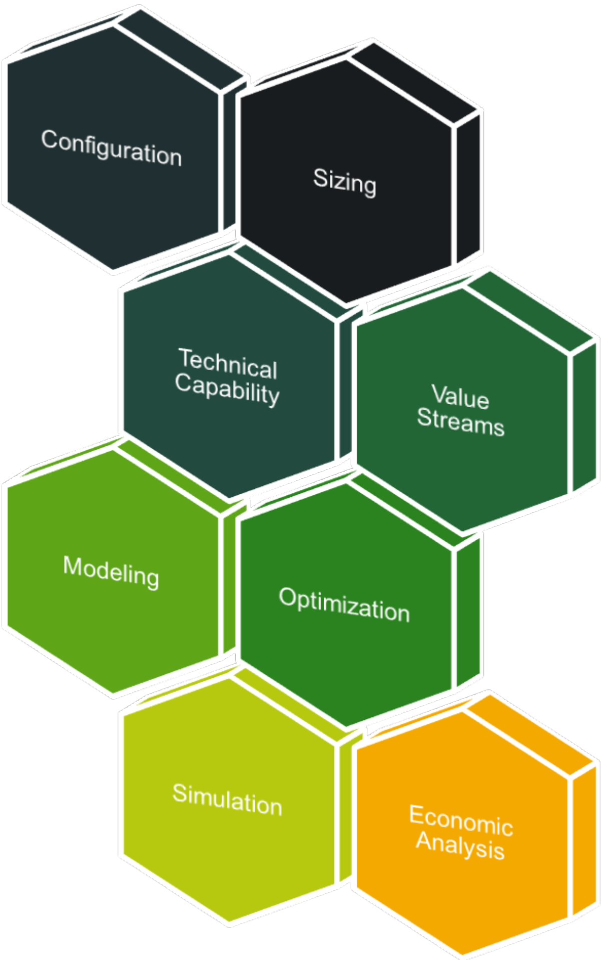
- Bulk energy, ancillary service, transmission-level, distribution-level, and end-user services

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



Modeling With a Good Balance Between Fidelity and Simplicity

- A set of equations and constraints, or tables representing operational flexibility and physical constraints
- Often black- or grey-box models at the system level
- Relaxed and approximated models

Batteries

- Operational flexibility
  - Constant vs varying efficiency
  - Static vs dynamic range
- Degradation effects
  - Loss of life
  - Degradation in performance

Pumped Hydro

- Fixed vs adjustable speed
- Various configurations: separate and reversible pump/turbine as well as ternary sets
- Unit- and plant-level hydraulic short circuit

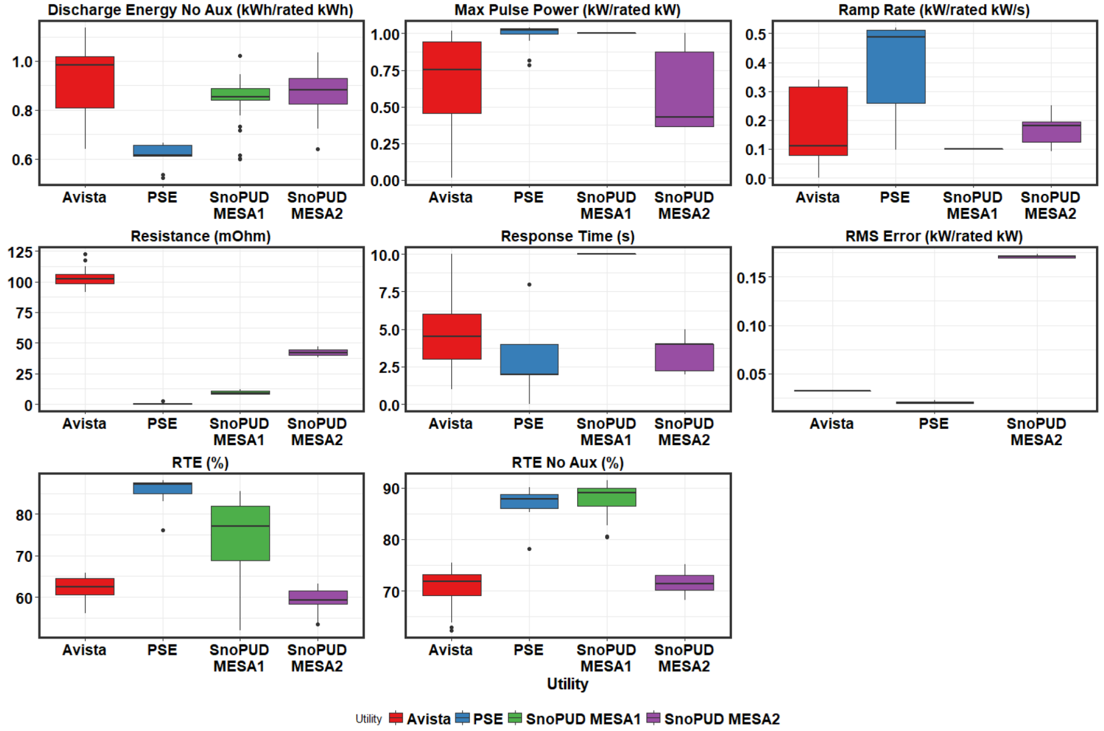
Hydrogen

- Multiple energy delivery pathways
- Component-level modeling
- Coupling among different pathways and grid services

Performance Quantification

Time series testing and operation datasets over multiple seasons or years

- Data requirement
- Quality, granularity, consistency
- Scarcity and insufficiency
- Privacy and security



DOE Rapid Operational Validation Initiative (ROVI)

- Driven by DOE National Labs
- Establish data collection framework and protocols for field deployments
- Performance prediction tools; engagement with a larger storage community

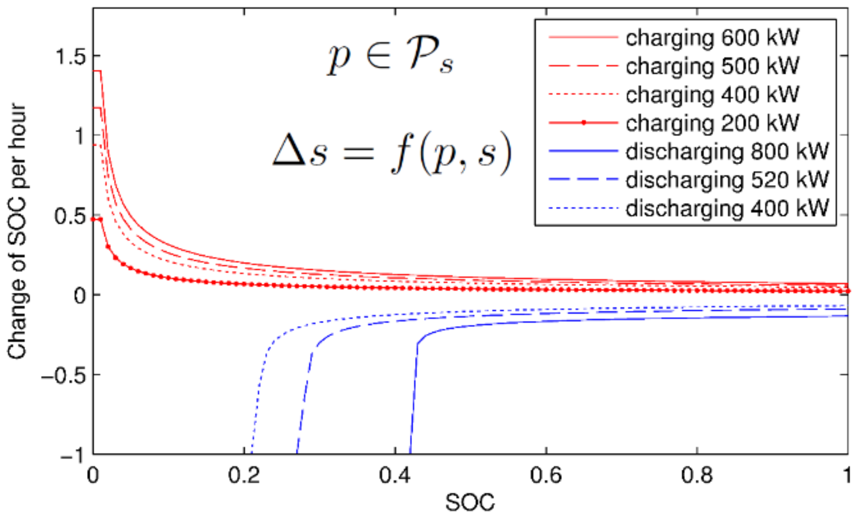
Bankable storage technologies

15- to 20-year financial grade performance projections with 1 year of combined testing and validation

https://www.energy.gov/oe/articles/us-department-energy-opportunity-rapid-operational-validation-initiative-flow-batteries

Model Construction

- Limitation of constant-efficiency models:
  - $[-p_{\min}, p_{\max}]$: incapable of modeling varying charging/discharging range
  - $E_{\max}$: inaccurate to represent energy capacity
  - η^{-},η^{+}: inaccurate to capture varying losses
- Constructing high-fidelity models through regression using testing data:
  - Power measured at batteries and the grid-coupling point
  - Battery direct current and voltage
  - Sate of charge estimated by battery management systems



The gradient boosting machine (GBM) algorithm for ranking predictor importance and determining coefficients.

D. Wu, P. Balducci, A. Crawford, K. Mongird, and X. Ma, "Building battery energy storage system performance data into an economic assessment," *in Proceedings of the IEEE Power and Energy Society General Meeting*, 2020.

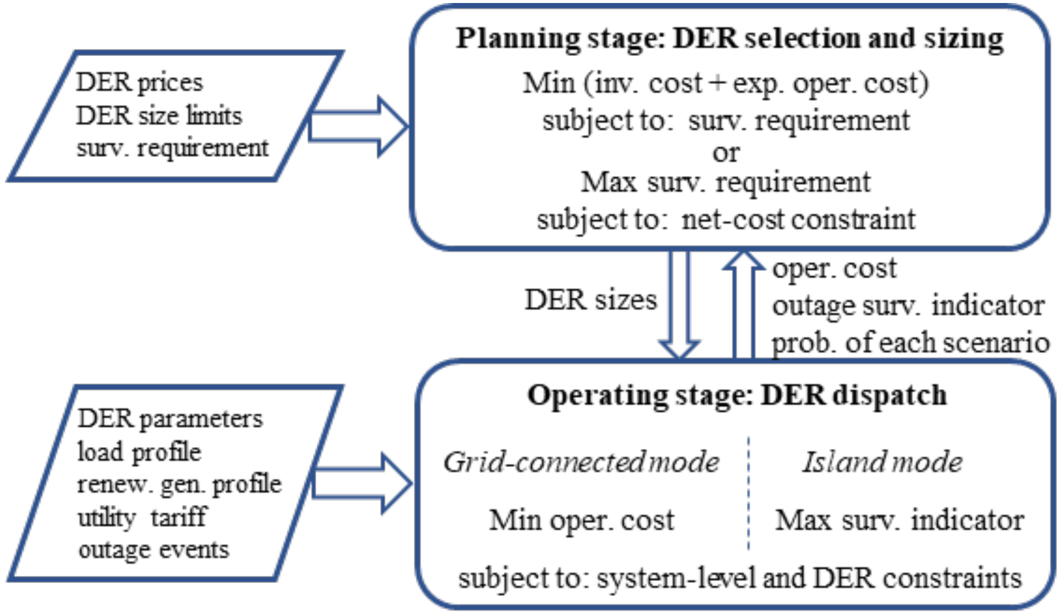
Stochastic Sizing

A framework for optimization that involves uncertainty:

- First stage: making “here-and-now” decisions before the realization of uncertain parameters is known (a single policy)
- Second stage: making decisions in response to each random outcome given the decisions made at the first stage (a collection of recourse decisions)

Probability distribution for uncertain parameters → A finite number of possible realizations (scenarios)

Deterministic equivalent of a stochastic problem



Two-stage stochastic DER sizing method

D. Wu, X. Ma, S. Huang, T. Fu, and P. Balducci, “Stochastic optimal sizing of distributed energy resources for a cost-effective and resilient microgrid,” *Energy*, vol. 198, May 2020, 117284

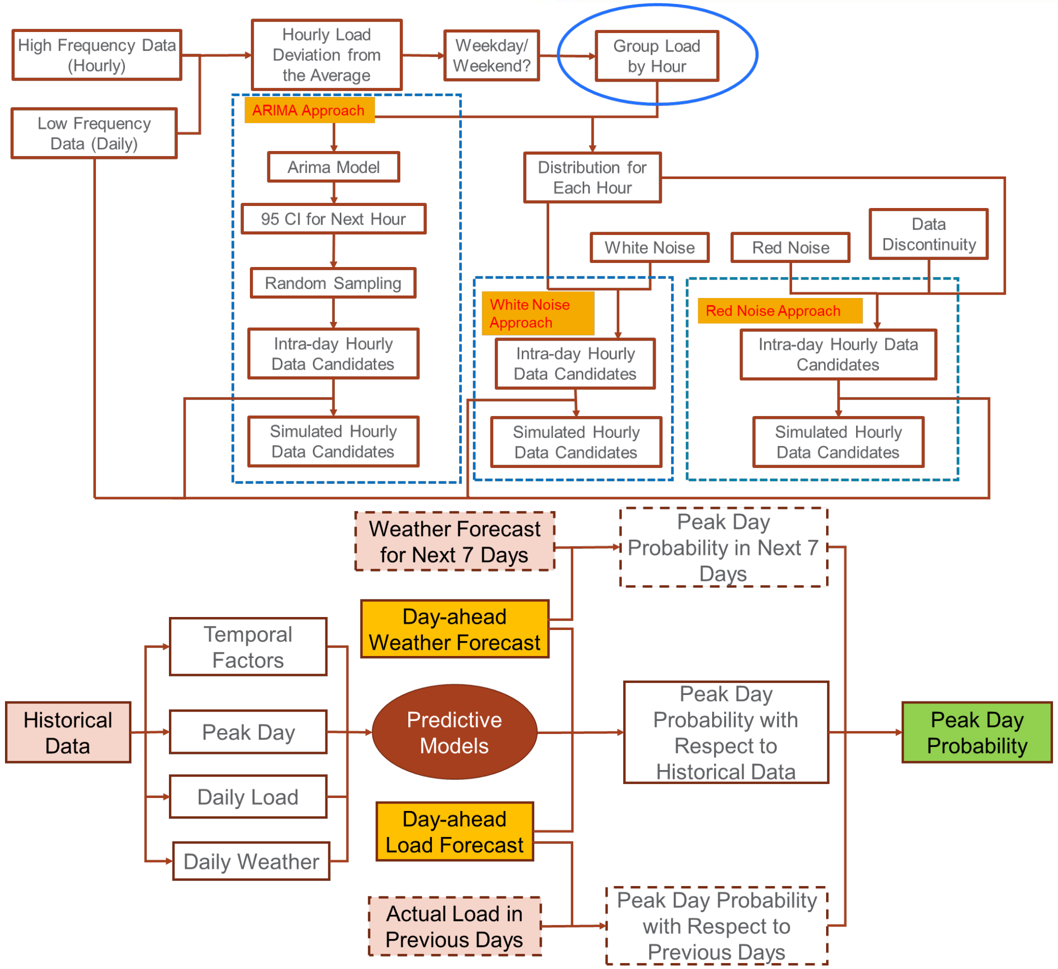
Data Analytics for Load Construction and Forecast

General requirements:

- Need to reproduce the overall statistical attributes from the datasets
- Need to capture changes in patterns by seasonality, weekday/weekend, and day/night

Methods:

- Exploratory data analyses: summary statistics extraction, pattern recognition, and spectral analysis of individual time series
- Data imputation or reconstruction
- Neural Network models



T. Fu, H. Zhou, X. Ma, Z. Hou, and D. Wu, “Predicting peak day and peak hour of electricity demand with ensemble machine learning,” *Front. Energy Res.*, vol. 10, Nov. 2022.

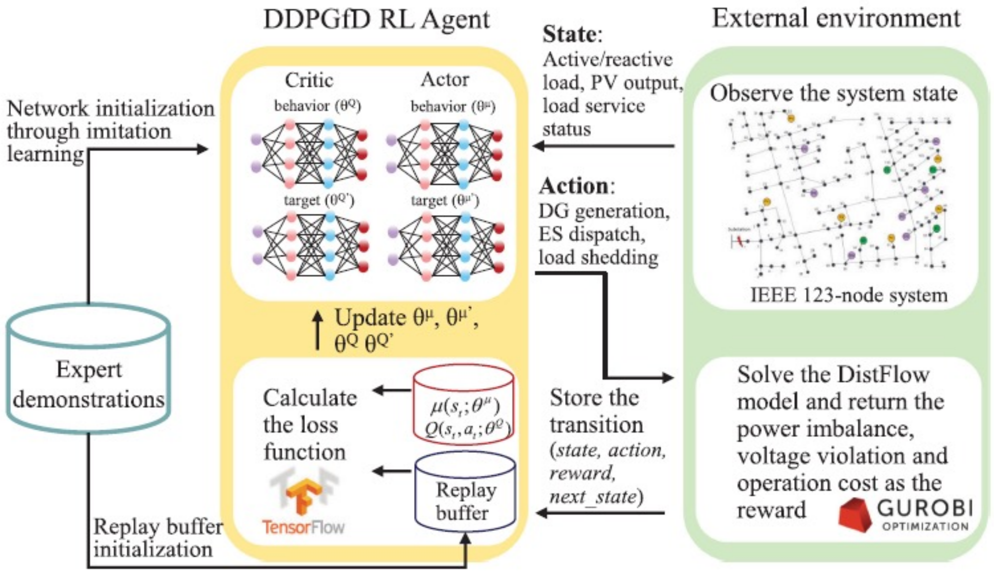
D. Wu, X. Ma, T. Fu, Z. Hou, PJ Rehm, and N. Lu, “Design of a battery energy management system for capacity charge reduction,” *IEEE Open Access J. Power Energy*, vol. 9, pp. 351–360, Aug. 2022.

Learning-based Control

Deep reinforcement learning from demonstrations to assist service restoration in islanded microgrids:

- Pre-training stage: imitation learning is applied to equip the control agent with expert experiences to guarantee acceptable initial performance.
- Online training stage: action clipping, reward shaping, and expert demonstrations are leveraged to ensure safe exploration while accelerating the training process.

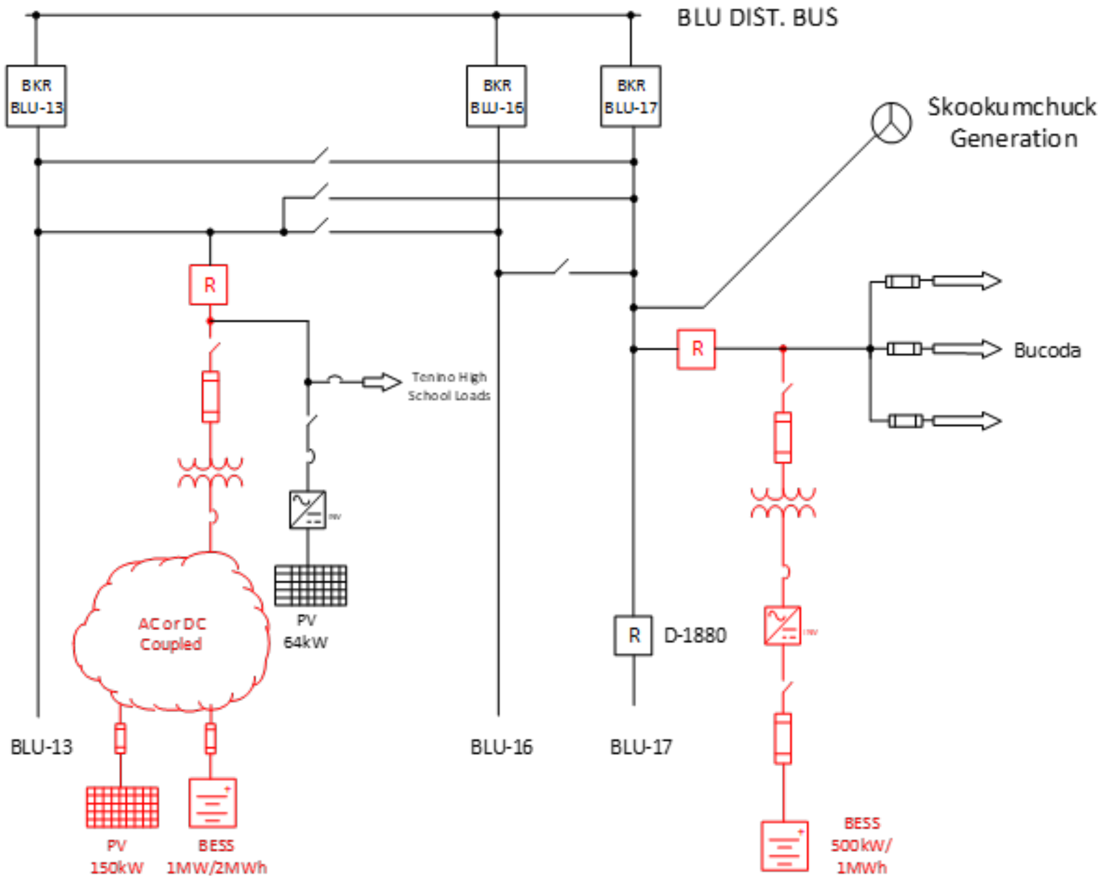
Data-driven methods face practical challenges such as potential hazards to microgrids during on-line training opportunities and insufficient on-line training due to low outage rates.

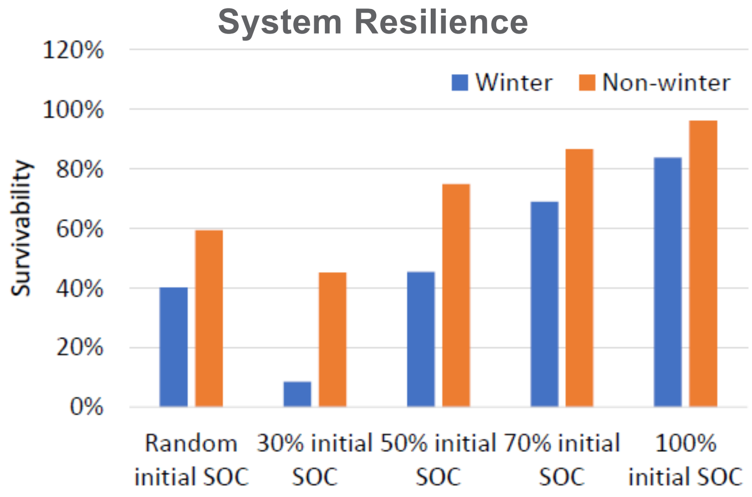


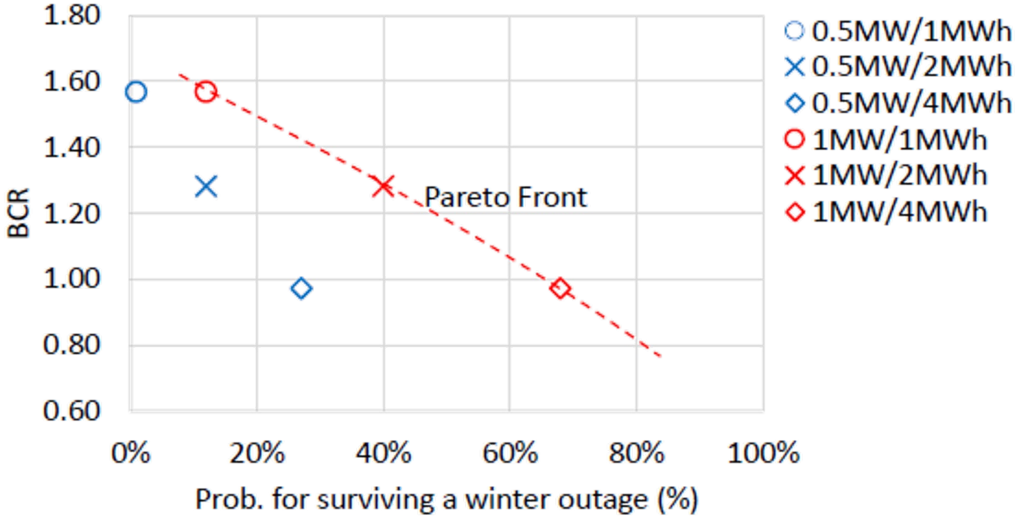
Y. Du and D. Wu, "Deep reinforcement learning from demonstrations to assist service restoration in islanded microgrids," *IEEE Transactions on Sustainable Energy*, vol. 13, no. 2, pp. 1062–1072, Apr. 2022.

A. Das D. Wu, and Z. Ni, "Approximate dynamic programming with customized policy design for microgrid online dispatch under uncertainties," *Int. J. Electr. Power Energy Syst.*, vol. 142, Nov. 2022, 108359.

PSE CEF III Tenino High School Microgrid







Y. Zhu, X. Ma, D. Wu, and J. Joseph, "A multi-objective microgrid assessment and sizing framework for economic and resilience benefits," *Proc. IEEE PES Gene. Meet.*, July 2023.

.

Conclusions and Future Work

- Storage-enabled microgrids are becoming critical solutions in enhancing resilience and offering the required flexibility and capacity
- The emergence of advanced data analytics and machine learning techniques opens up new opportunities for the design and operation of microgrids
- Additional research is needed to further take advantage of data analytics and machine learning in this field:
  - Risk-averse control
  - Extreme weather conditions
  - Rate design
  - Uncertainties
- It's crucial that all stakeholders come together to storage-enabled microgrid

Thank You

Di Wu
di.wu@pnnl.gov