Incorporate Operational Uncertainties into Energy Storage Valuation

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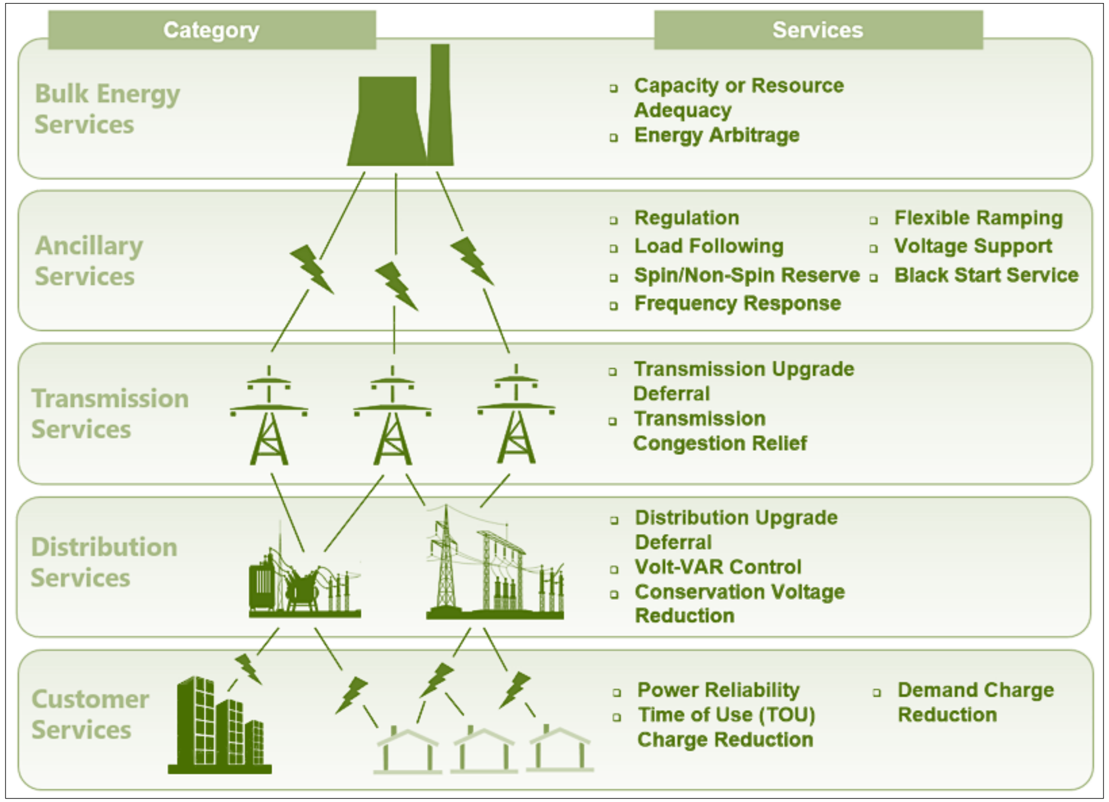
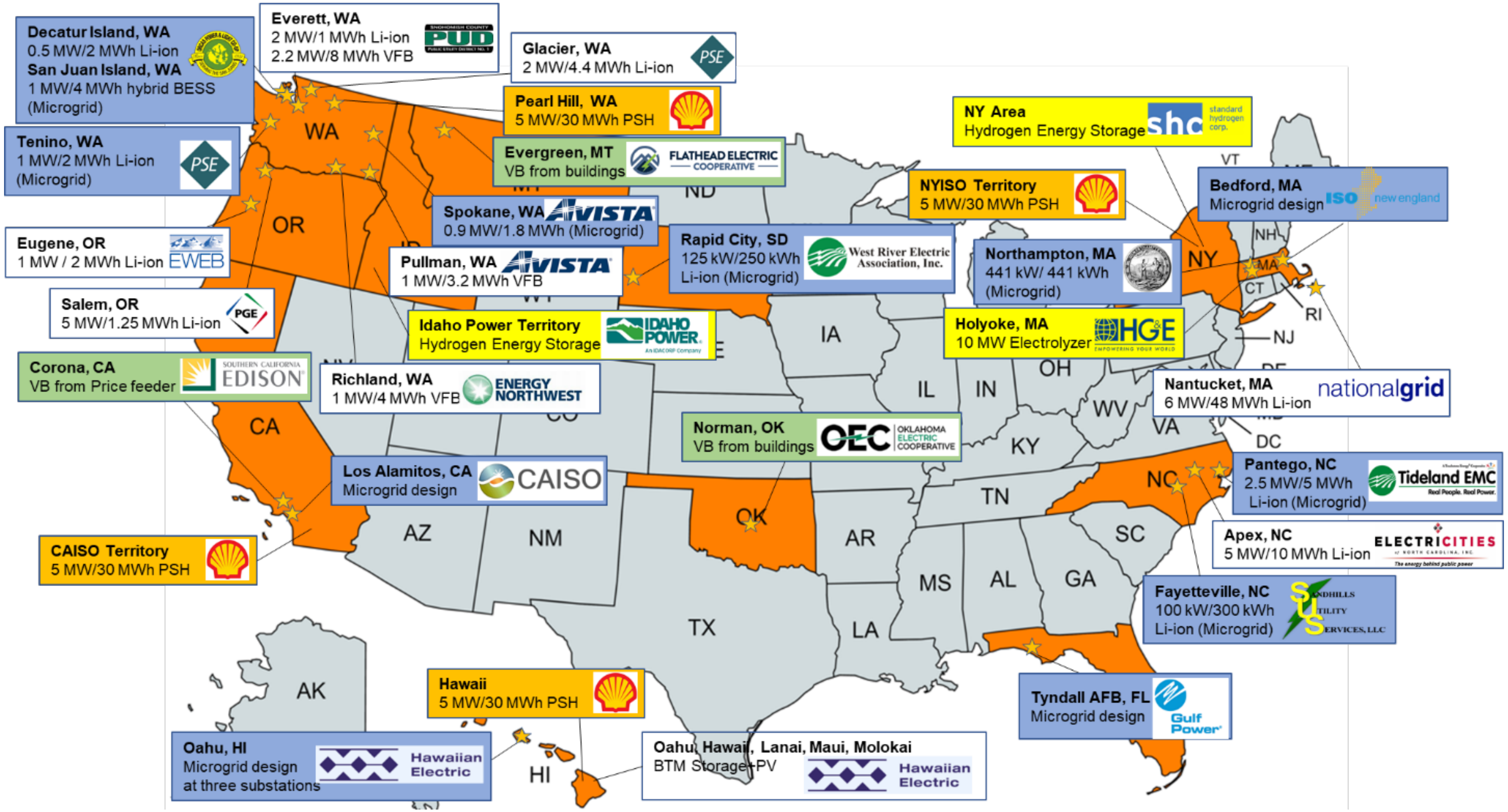
Storage Can Help Solve Problems in All Parts of The Grid

- Resource adequacy
  - System capacity
  - Flexibility
  - Local capacity
- Transmission adequacy
  - Support balancing load and generation
  - Support competitive markets
- Couplings between the two
  - Additional transmission capacity enhances the capacity value of variable generation
  - Energy storage and other resources are non-wire alternatives



PNNL Has Assessed Energy Storage at More Than 30 Sites



- Battery Energy Storage
- Microgrids
- Hydrogen
- Buildings as Storage
- Pumped Storage Hydro

Capacity and Resource Adequacy

Capacity markets and integrated resource planning ensure sufficient resources to meet the future demand

- Capacity markets:
  - Capacity payment is for participants offering supply capacity for ensuring resource adequacy.
  - Capacity charge is paid by load serving entities based on their coincident demand during system peak hours.
- Power purchase agreement: energy storage can be used to reduce capacity charge.
- Vertically integrated utilities: capacity value can be estimated based on the incremental cost of next best alternative investment (e.g., peaking combustion turbine) to meet the load and loss of load probability analyses.

ElectriCities Energy Storage Analytics

ElectriCities provides management services for about 90 public power municipalities in North Carolina, South Carolina, and Virginia.

- Capacity charge: based on the coincident demand during Duke Energy Progress monthly peak hours, with a demand rate at more than $20/kW-month
- ElectriCities does not know exactly when the peak hour will occur

Capacity charge reduction analytics:

- **Dispatch under uncertainty**
- **Optimal sizing**
- Coordination with other resources
- Benefits allocation among member utilities

Project Synopsis

Objective

Develop optimal dispatch and assessment methods to use BESSs for capacity charge reduction considering operational uncertainties and battery degradation.

Phases

Load analysis and modeling → Dispatch under uncertainties → Techno-economic assessment

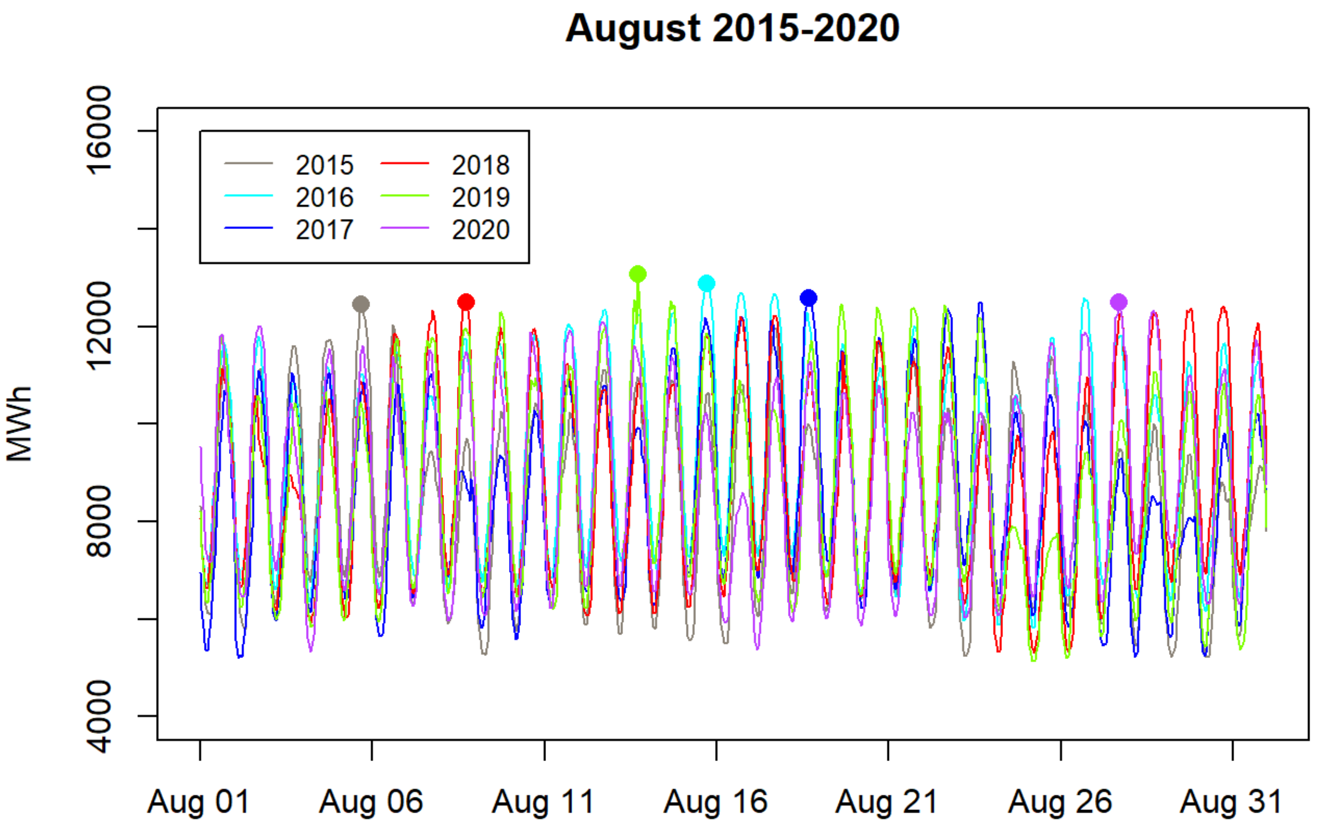
Team

- **PNNL**: Brings expertise in uncertainty quantification and energy storage modeling, optimization, and analysis
- **ElectriCities**: Brings deep operational experience, system modeling expertise, and required utility data
- **NCSU**: Brings expertise in load modeling, meter data analysis, and energy management systems
- **U.S. Department of Energy**: Brings energy storage expertise and program management

Challenges – Day-ahead Scheduling

- Cannot tell exactly whether tomorrow is the peak day (the day that contains the highest hourly load) of the month
- Dispatching the BESS for demand reduction on all “high-load” days causes unnecessary degradation

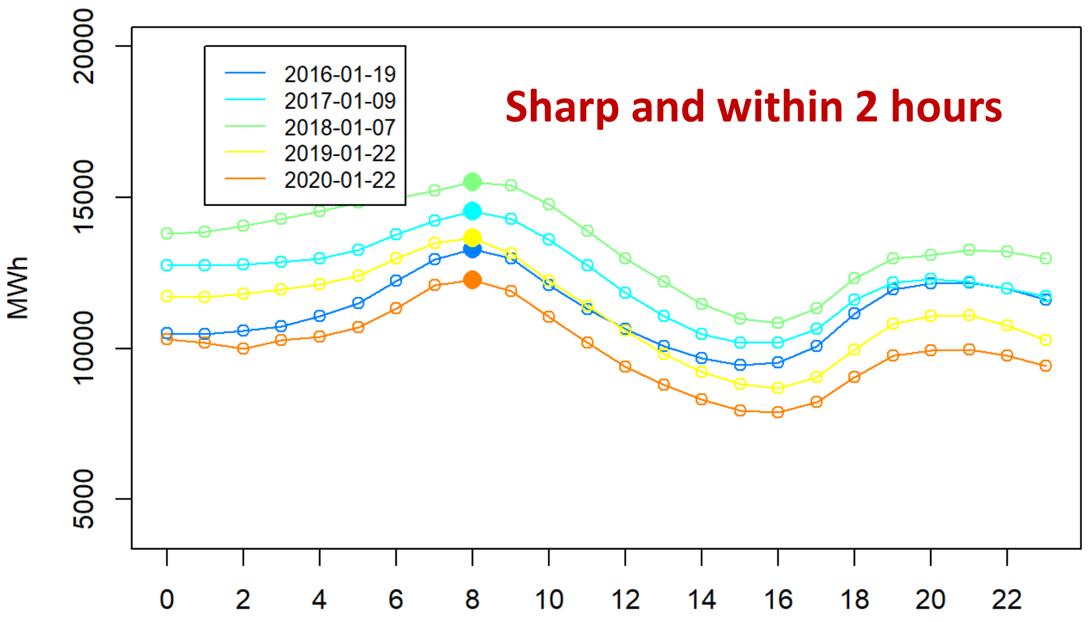
A strategy is needed to determine whether to dispatch a BESS for demand reduction day-ahead

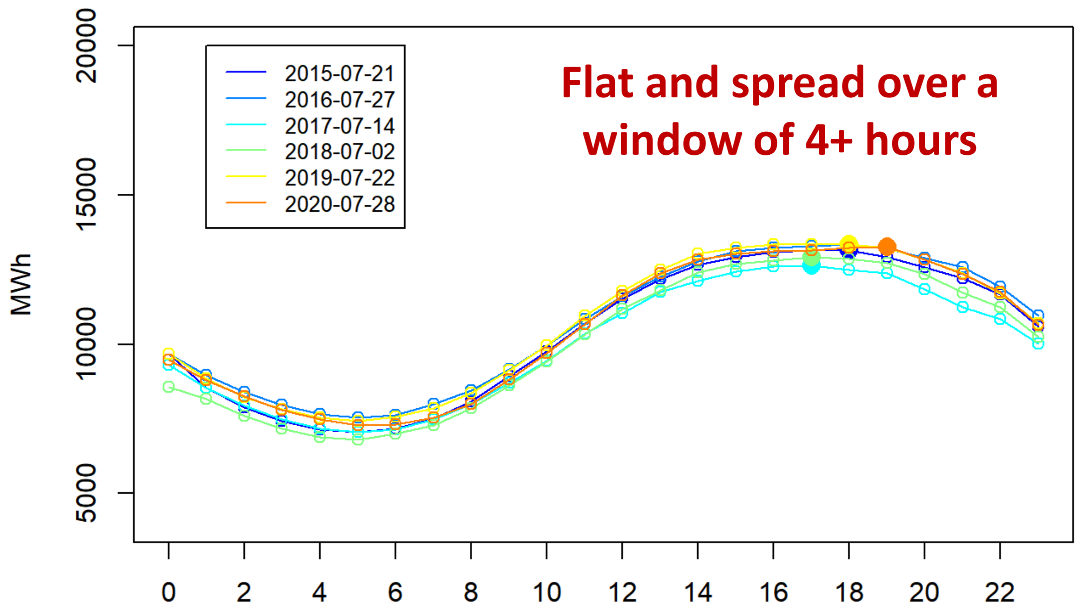


Challenges – Hour-ahead Scheduling

- Cannot tell exactly which hour is the peak hour
- Cannot dispatch the BESS at the maximum power for all “high-load” hours due to limited energy capacity

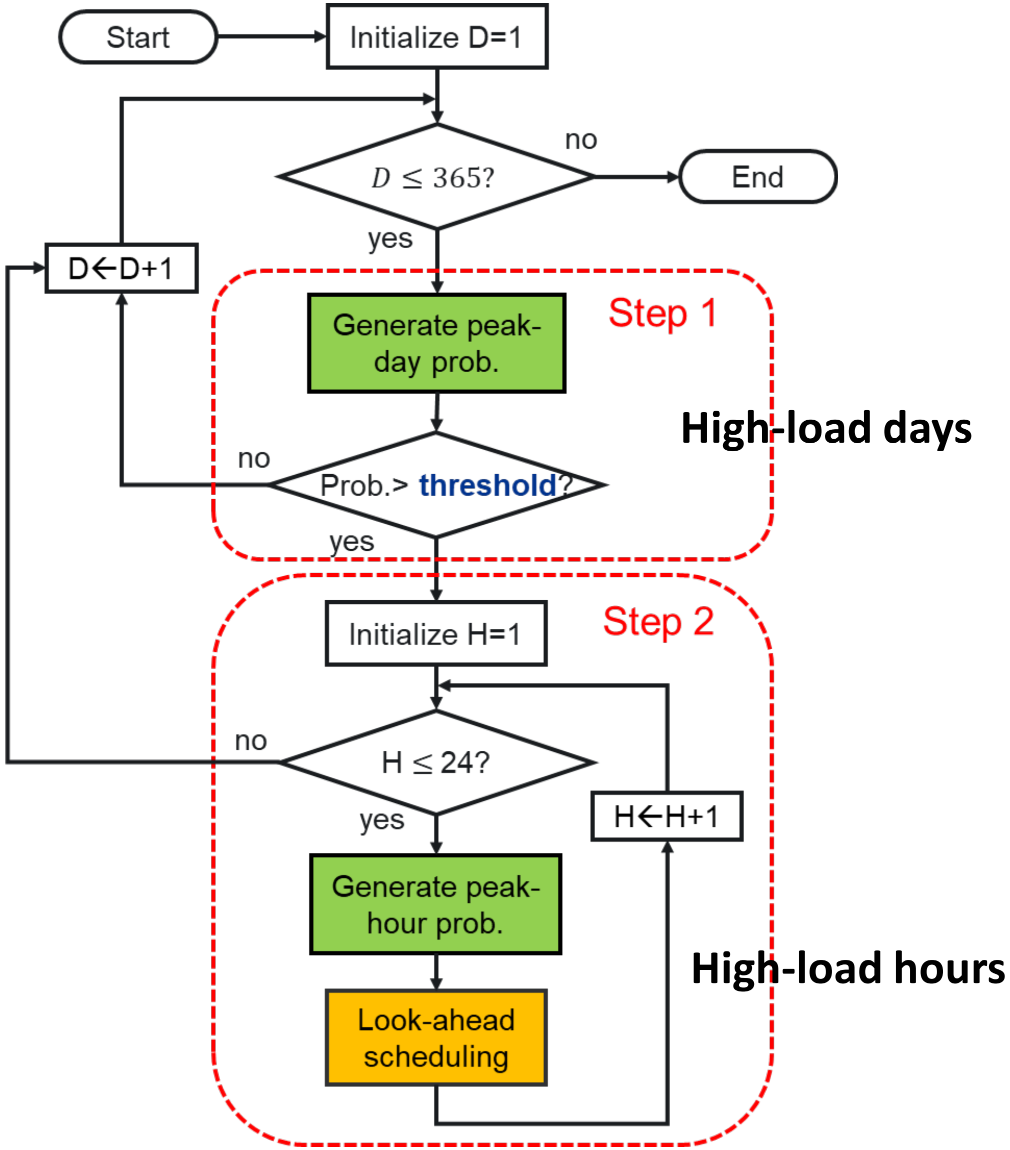
A method is required to determine discharging hours and power levels on the operating day





A Two-Step Hybrid Dispatch

- Two-step hybrid dispatch
  - Policy-based method to trigger a dispatch
  - Stochastic or robust dispatch
- Multi-time-scale load forecast models
  - Peak-day probability
  - Peak-hour probability
- BESS model used in MPC
  - Constant-efficiency or high-fidelity model
  - Degradation effects
- Methods for establishing thresholds
  - Searching through for-loop, bilevel-optimization, or learning-based methods



Techno-economic Analysis Parameters

- BESS parameters
  - Rated power: 5 MW
  - Round-trip efficiency: 88%
  - Duration: 1, 2, or 4 hours (usable energy)
  - Cycle life: a warranty of 100 cycles/year * 15 years = 1500 cycles
  - Calendar life: 20 years
- Testing Years: 2001, 2006, 2008, 2011, 2019, 2020
- Demand charge: $20/kW-month
- Real discount rate: 5%

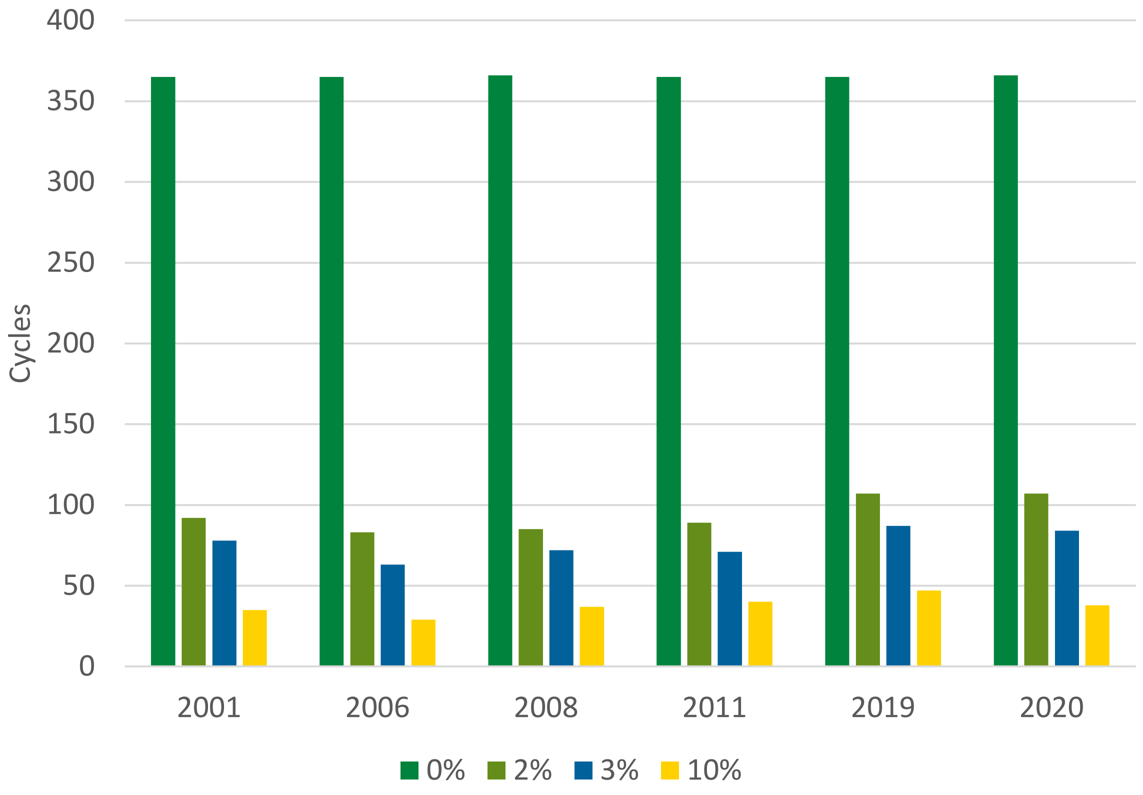
Key Findings

- The average annual cycle usage and BESS life only depend on the threshold used for peak-day probabilities.
- The threshold selection also affects the performance in capturing peak days.
- The duration of the BESS affects the performance in capturing peak hours.

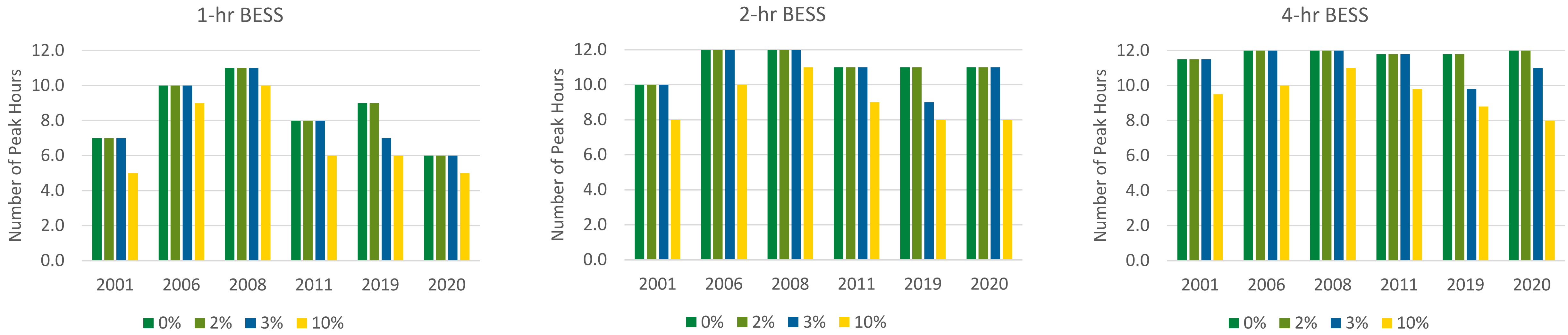
Threshold	Cycles	Life (yr)	Number of Peaks Captured		
			1-hour	2-hour	4-hour
0%	365	4.1	8.5	11.2	11.9
2%	94	16.0	8.5	11.2	11.9
3%	76	19.7	8.2	10.8	11.3
10%	38	20.0	6.8	9.0	9.5

Annual Cycle Usages

- Annual cycle usage varies by year, but the pattern of cycle usage versus threshold remains the same.
- The variability of the system load in different years is not the same, which affects the peak-day probabilities and their likelihood to exceed the threshold, and thereby the cycling frequency.



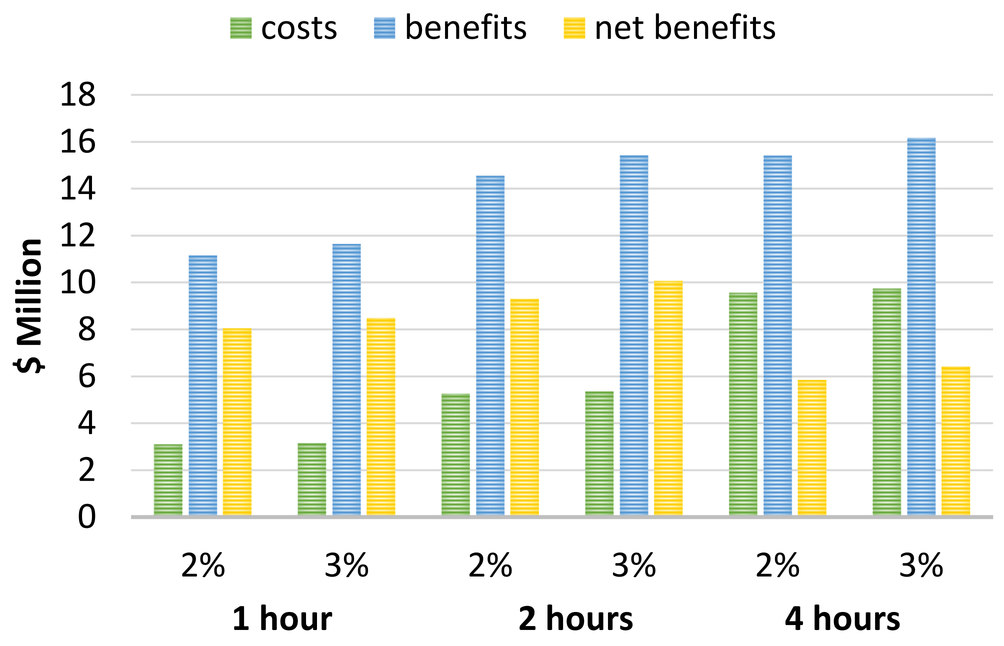
Number of Peaks Captured



- The number of peaks captured is the same for 2% and 3% thresholds for most of the testing years.
- With the 1-hour BESS, many peaks are missed, even with a 0% threshold where all missed peaks are due to the missed peak hours.
- The performance is significantly improved when increasing the duration to 2 and 4 hours.
- The model works well in summer and winter months, and the performance degrades in shoulder months, such as May and September.

Cost-benefit Analysis

- A threshold of 3% performs better than 2%, leading to 4-6% and 6-10% increments in benefits and net benefits, respectively.
- The BESS cost only depends on BESS duration while the benefits depend on both the duration and threshold.
  - Increasing the duration from 1 to 2 hours increases the benefits by about 30% and net benefits by about 17%
  - Further increasing the duration from 2 to 4 hours increases the benefits by about 5%, and net benefits decrease by about 40%.



Conclusions and Future Work

- Operational uncertainties need to be appropriately addressed in storage valuation
- Co-design is required to capture the interdependency between energy storage sizing and control design
- Storage capacity maintenance agreement may fail some advanced state-of-health models for storage valuation
- An optimal portfolio dispatch strategy is desired for a variety of resources (conventional generators, load control, voltage reduction, and energy storage) to account for dispatch order, dispatch duration, and movement of the system peak
- Modeling uncertainties become more important and challenging for long-duration energy storage

Thank You

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