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Koopman operator based battery energy storage system optimization framework

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PRESENTED BY

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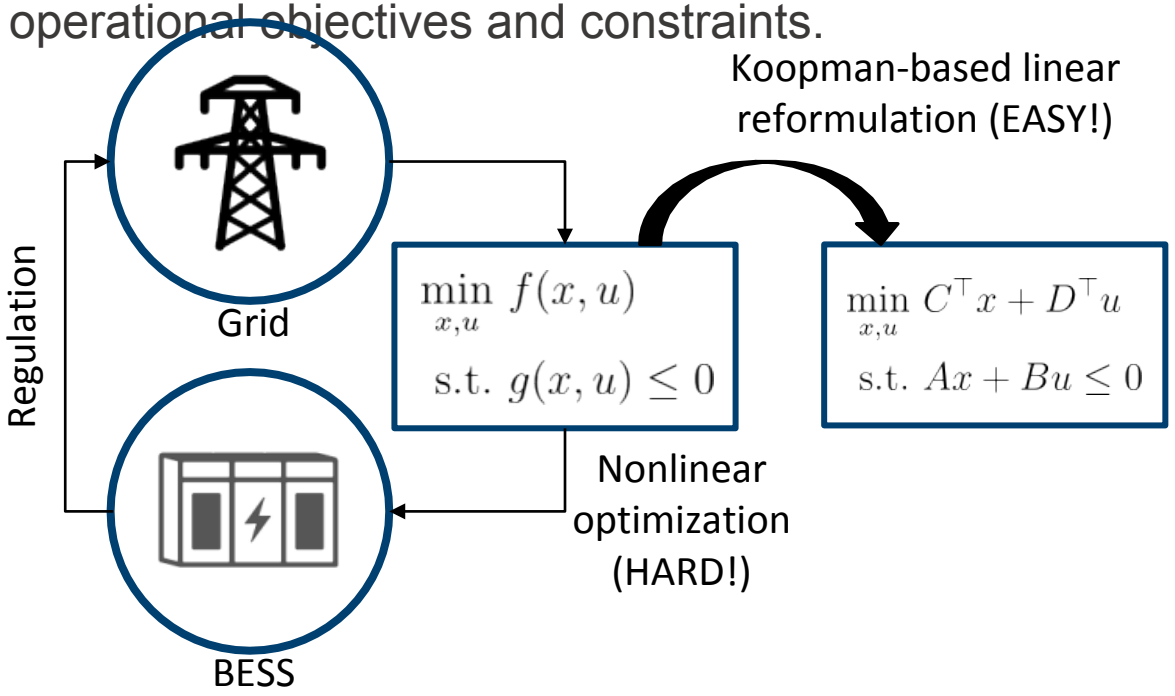
Motivation

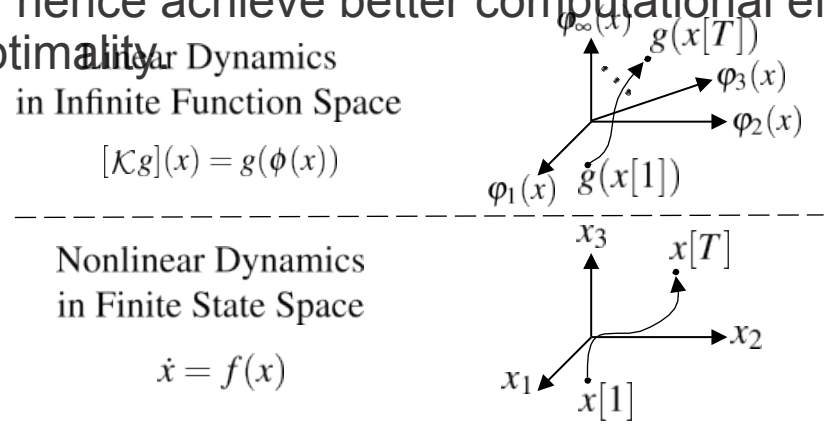
Optimal Battery Operation Problem:

- Battery energy storage system (BESS) is increasingly used in an electricity grid (e.g., frequency regulation) due to operational flexibility and fast ramping capability.
- However, lifetime of BESS is limited and is highly affected by the operation conditions.
- Thus, optimizing the operation of BESS is essential to minimize loss of BESS capacity while achieving other operational objectives and constraints.



Koopman framework for battery optimization problem:

- Challenge is to incorporate highly complex and nonlinear dynamical model of BESS into optimization problems, making it extremely difficult to solve.
- Objective is to adopt *Koopman operator* framework to convert original nonlinear BESS optimization problem into equivalent linear BESS optimization problem to improve computational efficiency and optimality.
- Koopman operator provides equivalent linear representation of original nonlinear system in function space, hence achieve better computational efficiency and optimality.

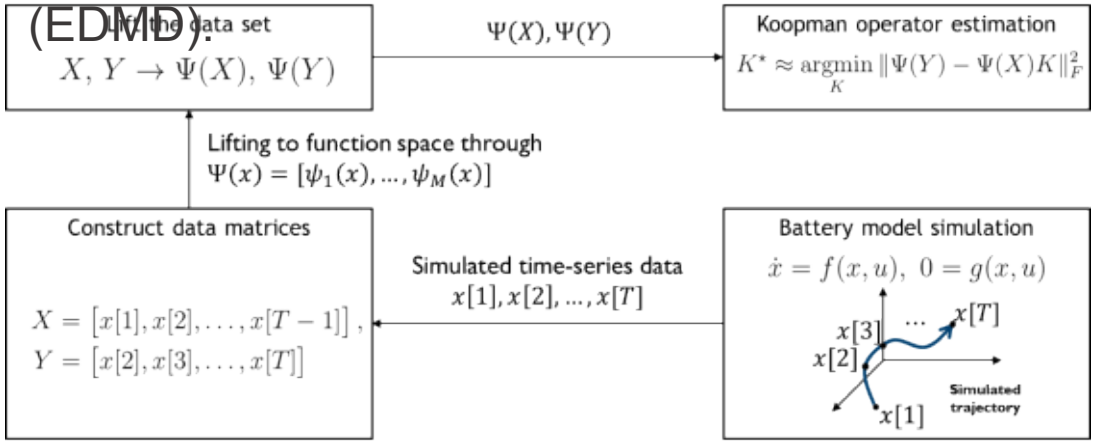


Conceptual description of Koopman operator

Algorithms and Simulations

Data-driven algorithm for Koopman operator estimation:

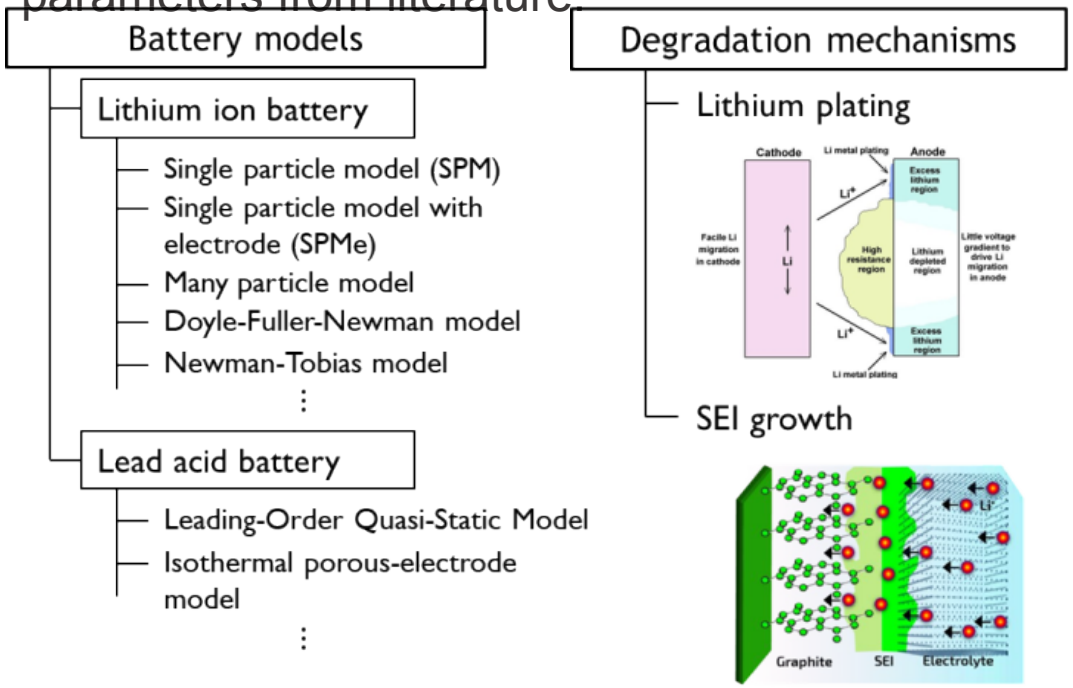
- Finding a Koopman operator analytically is difficult problem due to infinite dimensionality.
- Instead, we use time-series data to estimate a finite Koopman operator using data-driven algorithm called *extended dynamic mode decomposition* (EDMD).



Data-driven EDMD algorithm for Koopman operator model estimation

PyBamm: open-source battery simulation software:

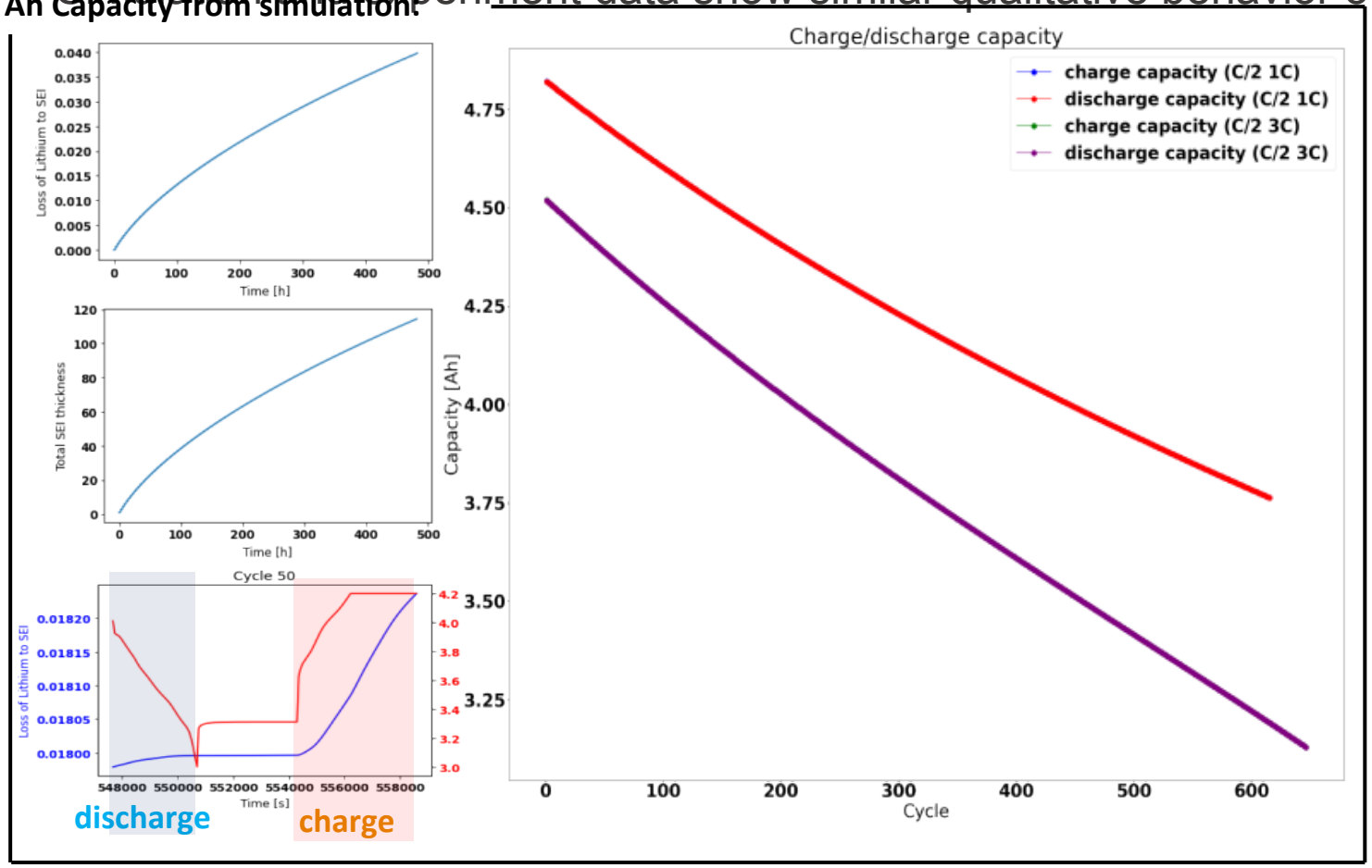
- As discussed previously, Koopman operator model estimation requires time-series simulation data.
- PyBamm is an open-source battery simulation model which provides various battery models (e.g., SPM, DFN), degradation mechanisms, and a rich set of parameters from literature.



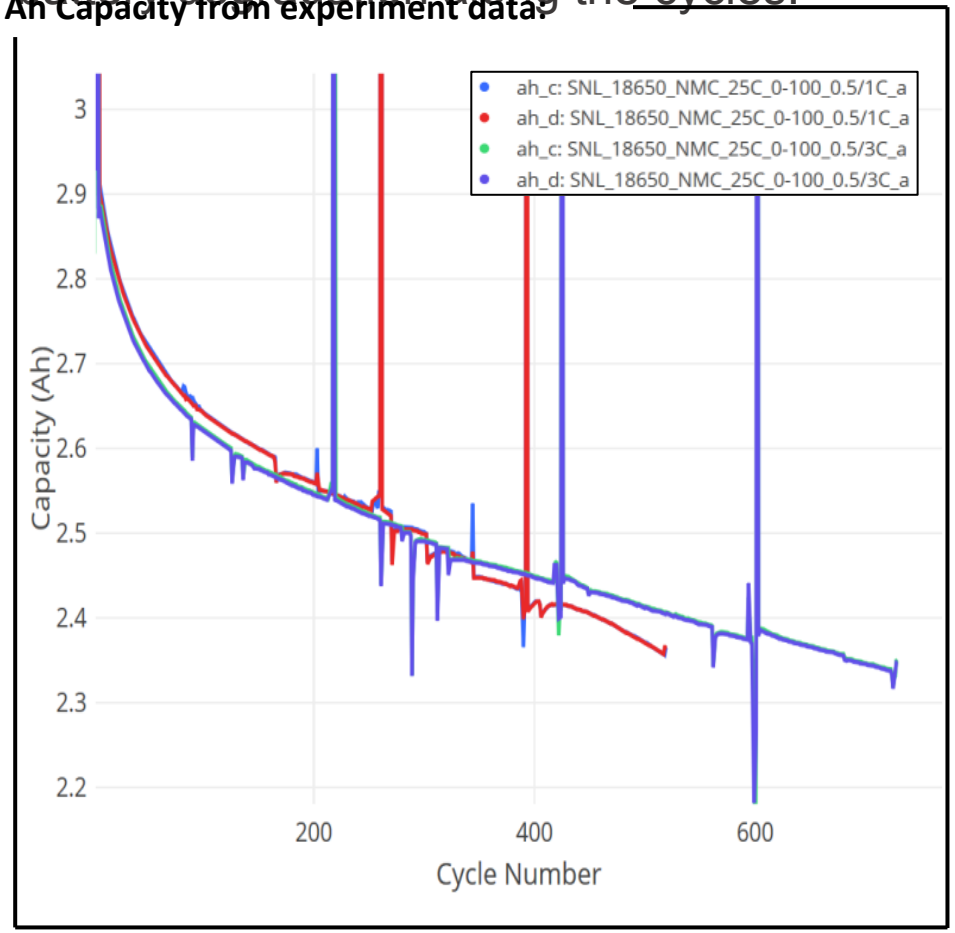
Battery Simulation Example using PyBamm

- PyBamm's long-term simulation of NMC cell using single particle model (SPM) with degradation due to SEI growth mechanism with parameter sets referring to Chen et. al., 2020 from literature.
- In the example, a cycle consists of combinations of charging steps {1C, C/2} and discharging steps {1C, 3C}.
- Simulation and experiment data show similar qualitative behavior of battery degradation along the cycles.

Ah Capacity from simulation:



Ah Capacity from experiment data:



Summary

Accomplishment

- Working paper on optimal BESS operation in frequency regulation market based on Koopman operator framework.
  : H. Choi, V. D. Angelis, Y. Preger, “Optimal Economic Operation of Battery Energy Storage in Frequency Regulation Market using Koopman Operator”, in Preparation.
- Adopt and verify PyBamm software package for long-term battery degradation simulation capability and experimental data verification.

Next Steps

Simulation & Verification

- Verify simulation results by fine-tuning simulation model parameters to match with experimental data.
- Repeated long-term simulations to get time-series data for different input conditions.

Algorithm development

- Implement EDMD algorithm to estimate linear Koopman operator model which represents battery surrogate model using simulated data sets.
- Verify the model accuracy by comparing to simulation and experiment data.
- Develop an algorithm to construct multi time-scale Koopman operator model (i.e., fast dynamical model +

Battery Optimization

- Incorporate the linear Koopman model into the frequency regulation optimization problem to minimize the degradation of battery while maximizing revenue from regulation market.
- Verify and compare optimal solutions between original nonlinear problem and reformulated problem.

Acknowledgements

Valerio De Angelis

Yuliya Preger

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