PhD student: Mattia Ribera

Battery modelling for SOH estimation and innovative HESS solution to enhance lifetime of battery-based charging station

Tutor: Prof. Diego Iannuzzi

Cycle: XXXVIII Year: II

Candidate's information

Before PhD:

- Master's degree in Automation Engineering at the University of Naples Federico II
- Master's degree thesis on EV charge scheduling for UFCS
- Designed a Control firmware for a DC-DC converter for EV mobile charger

PhD course:

- PhD start date: 01 November 2022
- Scholarship type: UNINA
- Electrical engineering group (CRIAT group)

Summary of study activities

- The research activities are focused on electrochemical storage systems based on lithium technology.
- In particular, the studies are related to test SOH estimation methods and highlight pros and cons. Different batteries were used to assess the performance of the proposed approaches. The techniques tested during this period were model-based and data-driven

Summary of attended courses

- Ad hoc PhD courses :
  - Percorso per il rafforzamento delle competenze sulla progettazione europea
  - Numerical Methods for Thermal Analysis, Modeling and Simulation: Application to Electronic Devices and Systems”
  - How to boost your PhD”
  - Using Deep Learning Properly
  - Operational Research: Mathematical Modelling, Methods and Software Tools for Optimization Problem
  - Machine Learning for Science and Engineering Research
- Courses borrowed from MSc curricula:
  - Sviluppo di convertitori e dispositive di accumulo per smart grids

Summary of attended conferences

- Conferences attended:
  - Advanced Battery Power - Kraftwerk Batterie, April 2024 (virtual attendance)
  - International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), June 2024 (author presenter)
  - International Conference on Artificial Intelligence & Green Energy (ICAIGE24), October 2024 (Virtually attended as presenting author)

Research activity

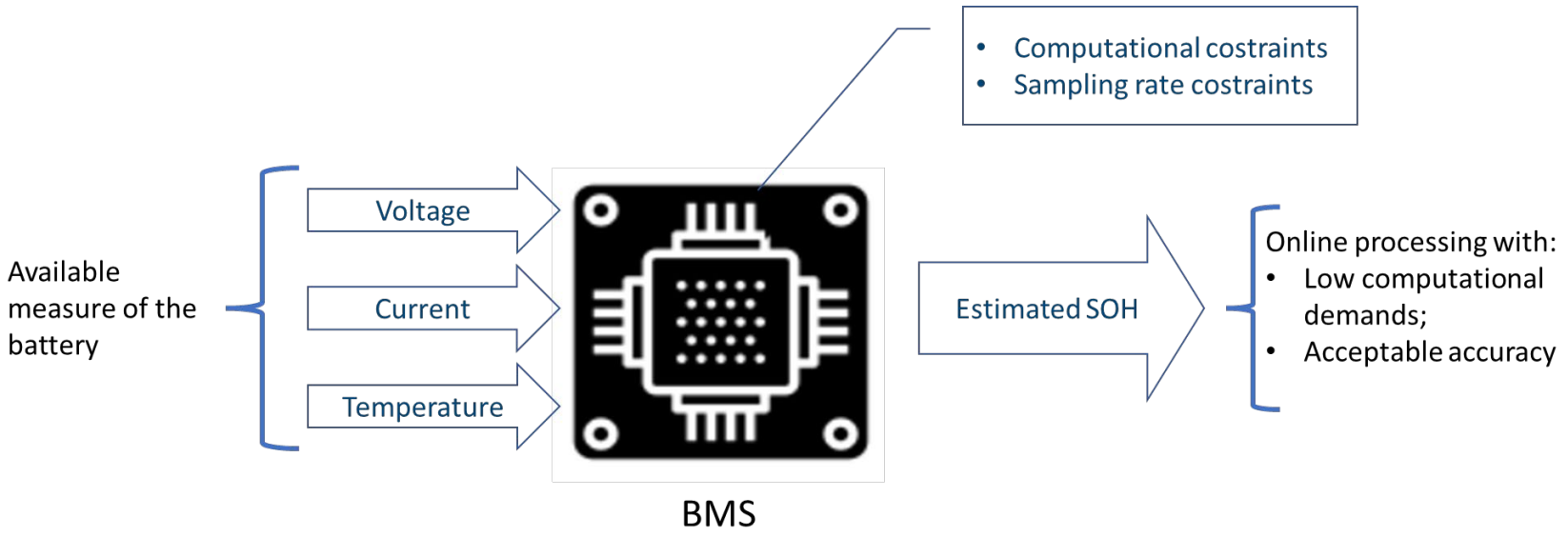
1. *Research activity progress on battery modelling techniques for State of Health estimation*
2. *Performance evaluation of data-driven SOH estimator trained with few data*

Battery SOH Estimation: Overview

- ***Battery's problem***

Battery degradation occurs both during stationary periods and operation, depending on various stress factors. The amount of available charge of a battery, during its operative life, is related as a health index, properly defined **State of Health (SoH)** of battery.

The main problem is, how to estimate SOH levels for embedded solutions.



Battery modelling and SOH Estimation: Overview

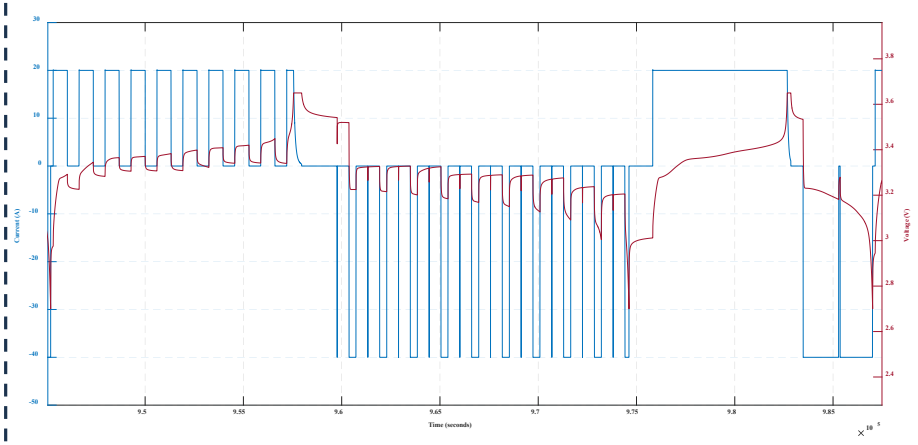
- ***Target***

The research activity goal is to define a good modelling approach to characterize a lithium battery at different ages and provide an SOH estimation algorithm.

- ***Methodology to test***
  - Linearize the battery at fixed operating conditions (SoC, SoH and temperature) and store the models in a database;
  - Compare the reconstructed behavior to the measured behavior to evaluate the estimation's goodness of fit
- ***Data available for model-based estimator evaluation***
  - Data of 21 aged NMC cells (source from *University of Michigan*)
  - Data of 2 aged LFP cells (source from *FAAM company*)
  - Data of LCO cell (source from *Politecnico di Milano*)

Battery modelling and SOH Estimation: Overview

- ***Model based Methodology***



HPPC identification dataset $\{V_{BATT\,SOC,SOH,Temp}(k)\}$

Capacity \ q		
	$V_{BATT\,1,1,1}(k)$	$V_{BATT\,2,1,1}(k)$ ...
	$V_{BATT\,1,2,1}(k)$	$V_{BATT\,2,2,1}(k)$ ...
	...	...

OCV acquisition during battery relaxation

OCV look-up table $\{OCV_{SOC,SOH,Temp}\}$

Capacity \ q		
	$OCV_{1,1,1}$	$OCV_{2,1,1}$ ...
	$OCV_{1,2,1}$	$OCV_{2,2,1}$ ...
	...	...

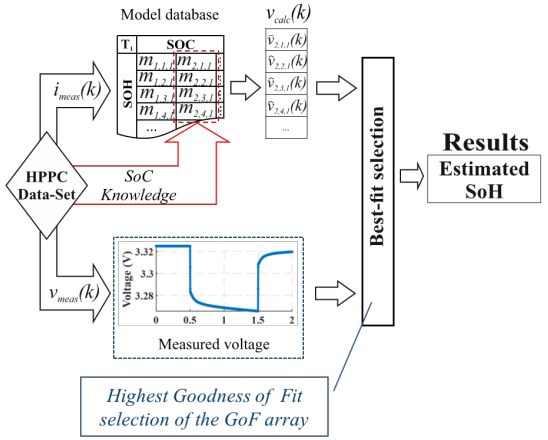
$$V_{d\,SOC,SOH,Temp}(k) = V_{BATT\,SOC,SOH,Temp}(k) - OCV_{SOC,SOH,Temp}$$

ARMAX identification

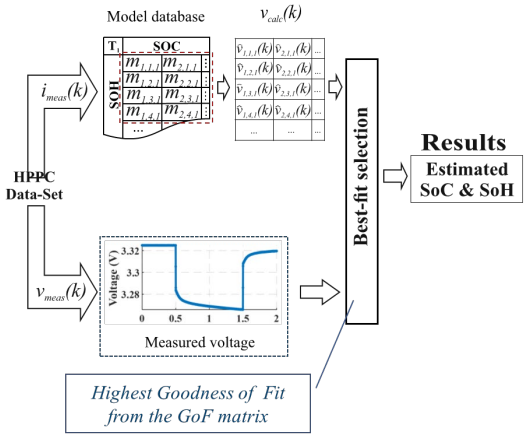
ARMAX model table $\{m_{SOC,SOH,Temp}\}$

Capacity \ q		
	$m_{1,1,1}$	$m_{2,1,1}$ ...
	$m_{1,2,1}$	$m_{2,2,1}$ ...
	...	...

SOH Estimation



SOC and SOH joint Estimation



Battery modelling and SOH Estimation: Overview

- ***Model based Methodology***

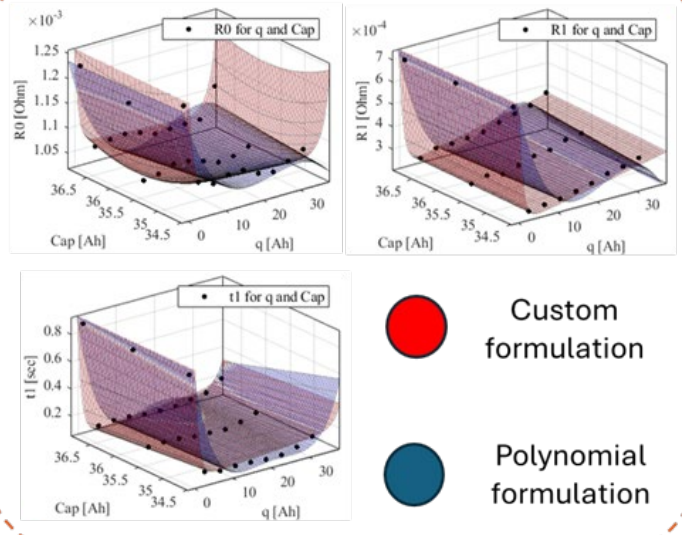
1) Characterization process

IDENTIFICATION TABLE

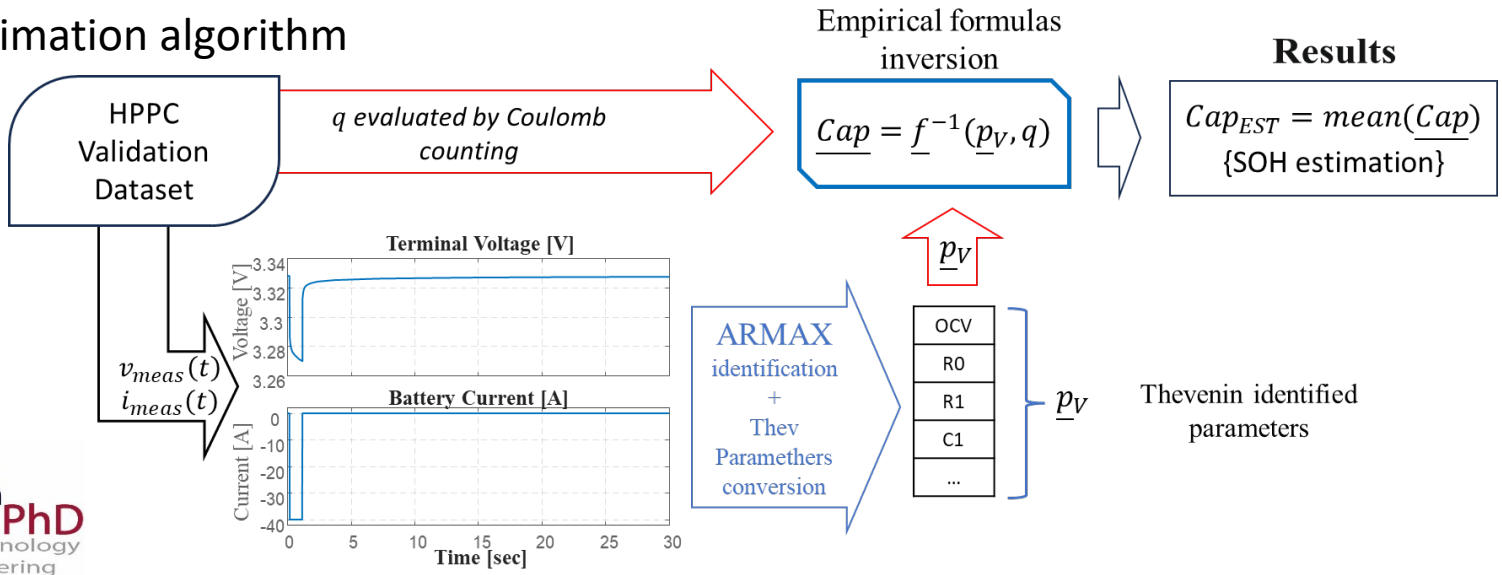
ARMAX model table

	q_0	q_1	q_2
Cap_1	$m_{1,1,1}$	$m_{2,1,1}$	...
Cap_2	$m_{1,2,1}$	$m_{2,2,1}$	...
Cap_3	...	...	

ECM EMPIRICAL MODELS



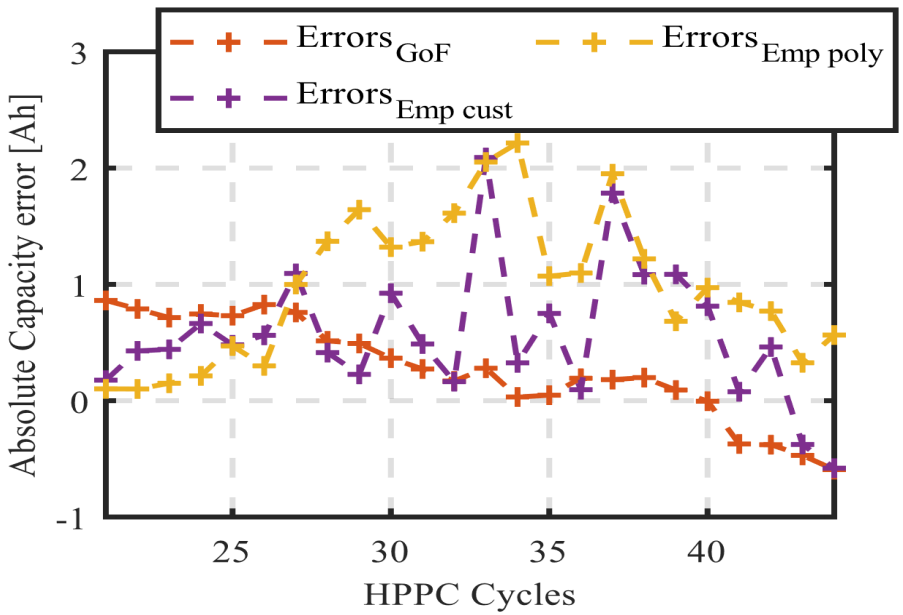
2) Estimation algorithm



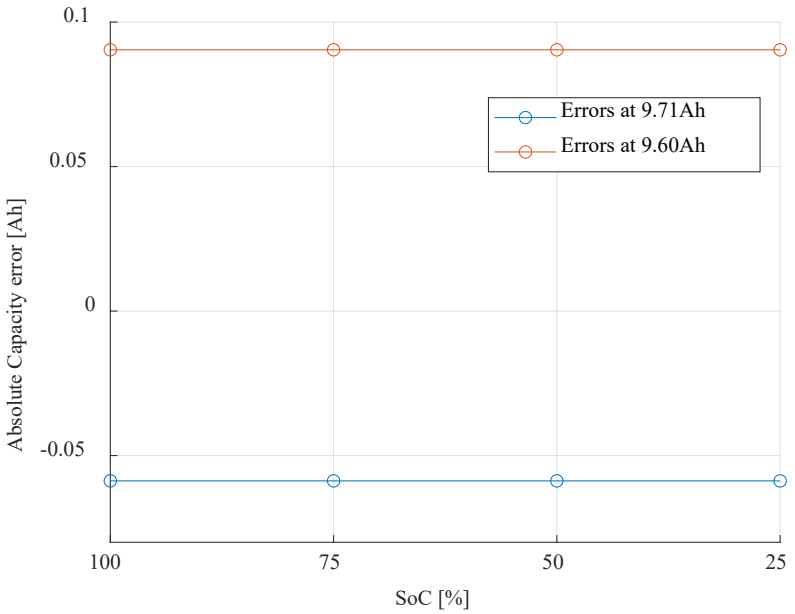
Battery modelling and SOH Estimation: Results

- ***Batteries used and results***

LFP results



LCO results

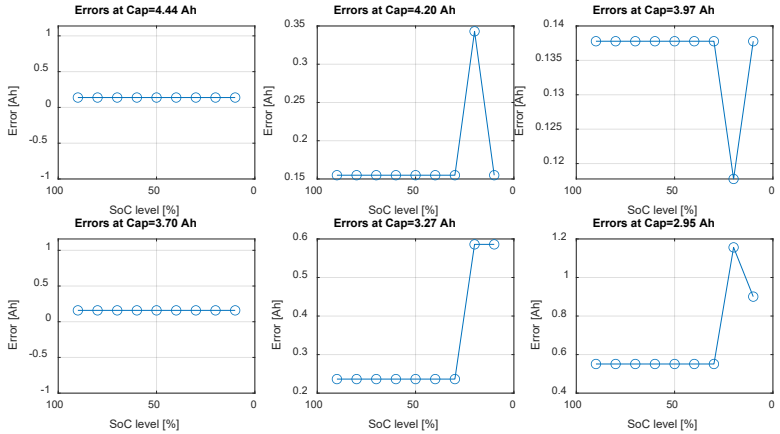


Battery modelling and SOH Estimation: Results

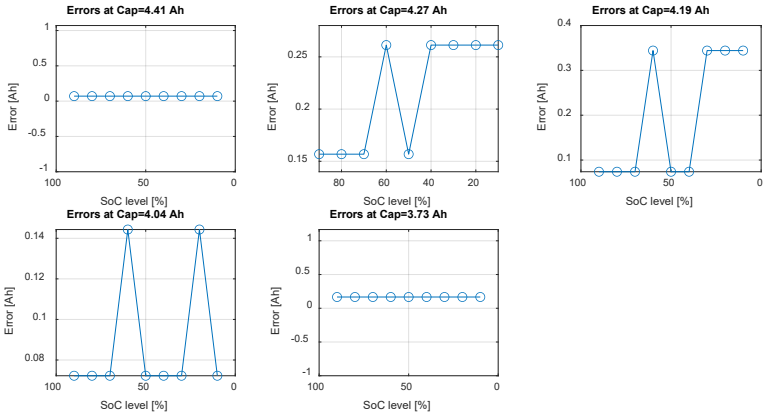
- ***Batteries used and results***

NMC results

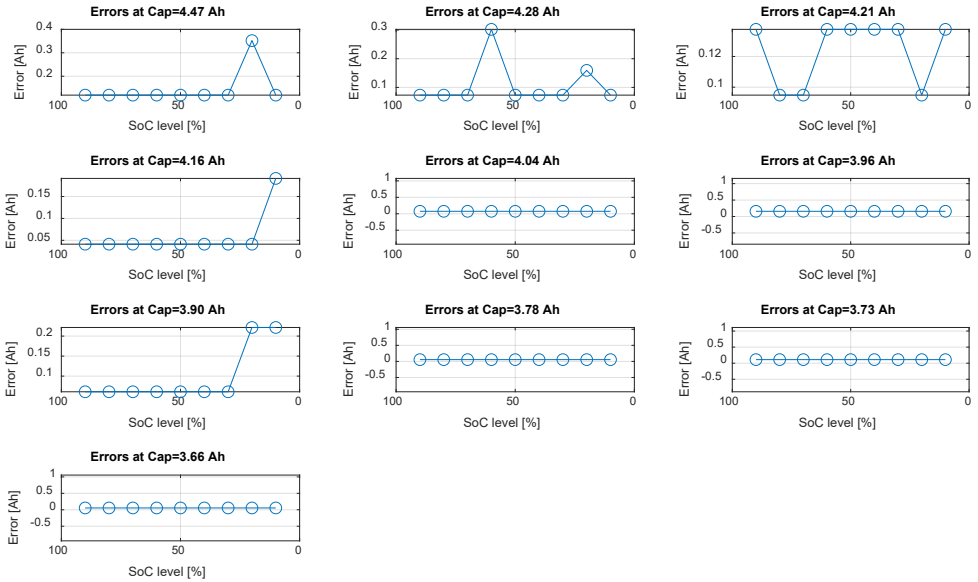
NMC Cell 1



NMC Cell 3

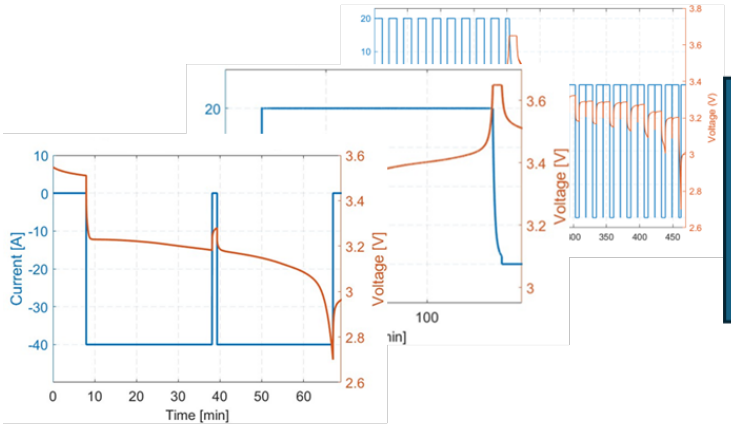


NMC Cell 2

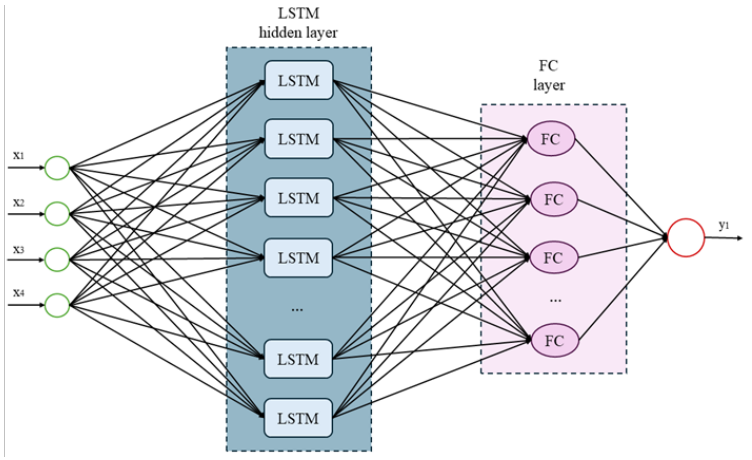


ANN for SOH Estimation: Overview

- ***Methodology***
  - ✓ **Literature Review**: Research on Artificial Neural Networks (ANN) applied to the field of electrochemical batteries.
  - ✓ **Method Acquisition**: Learning the methods for implementing neural networks in MATLAB, including:
    - ❖ Defining ANN architecture
    - ❖ Tuning hyperparameters
    - ❖ Automating repeated training sessions
    - ❖ Processing performance metrics of trained networks
  - ✓ **Application of Knowledge**: Utilizing the acquired knowledge to identify the "optimal" network for estimating the remaining capacity of Lithium Iron Phosphate (LFP) batteries

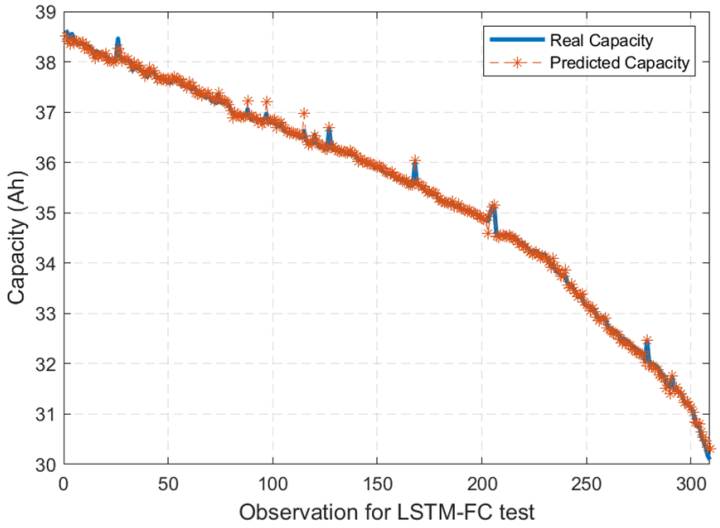


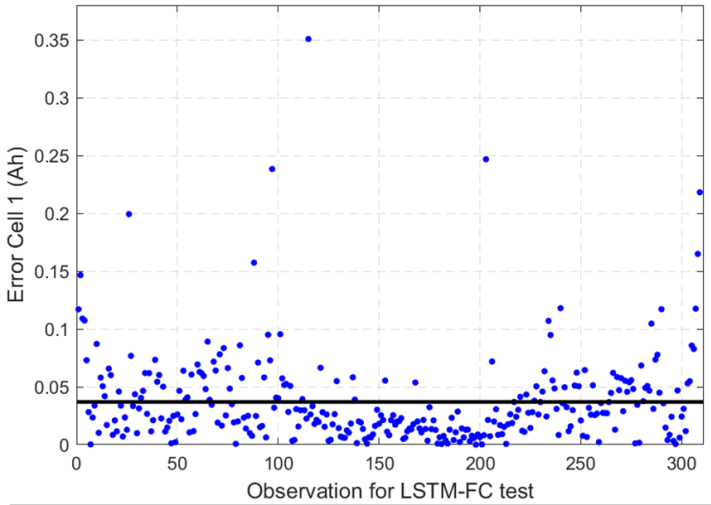
Training/
Validation/
Test



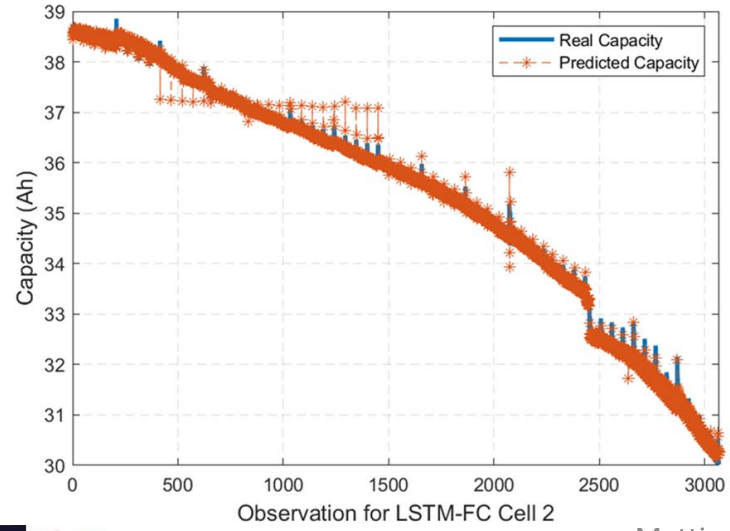
ANN for SOH Estimation: Results

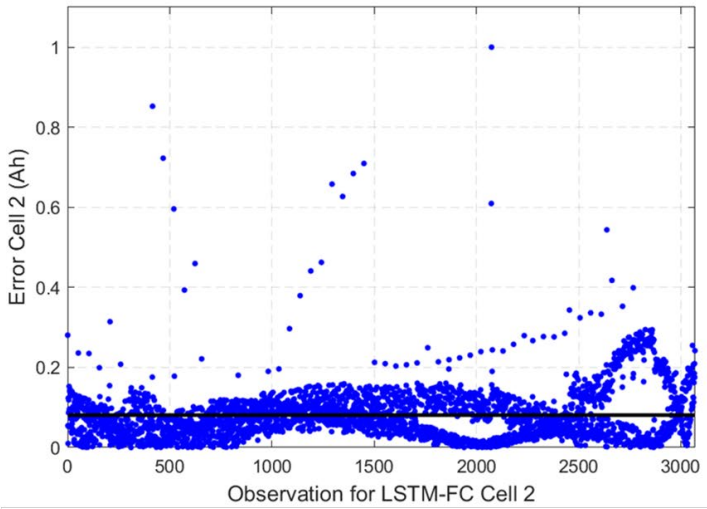
- Results from the test dataset of Cell 1





- Results from the complete dataset of Cell 2, never used during training





Research activities: Future developments

- **Experimental Setup Upgrade:**

  I am planning to enhance my experimental setup to enable parallel testing of multiple batteries under precisely controlled temperature conditions.

- **Model-Based Estimators Stress Testing:**

  The model-based estimators will be stressed using data from aged batteries cycled under different conditions. The available and future data collected from our setup will be utilized to evaluate SOH performance and to define more complex models that account for aging stress conditions.

- **Data-Driven Models for State of Health (SOH):**

  In my ongoing efforts to develop data-driven models for SOH estimators, I will investigate their performance using a comprehensive dataset from various studies. Additionally, I will explore the limitations of current methods, including implementation challenges and issues with generalizing the estimators. By addressing these drawbacks, I aim to find a balanced approach that can be effectively implemented in real-world applications.

- **International Collaboration:**

  During my collaboration with the University of Michigan, I will focus on estimating the aging state of batteries using various approaches. I plan to test both the estimators with the extensive dataset of aged NMC batteries provided by the American university.

  This dataset, which includes batteries aged under multiple operating conditions, will be invaluable for refining my estimators and enhancing their accuracy.

Research Products

[C1]	G. Brando; D. Iannuzzi; M. Ribera *"State of health estimation of cycle-aged cylindric LFP batteries using ARMAX modeling"* 2024 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Ischia, Italy
[C2]	A. Andreotti; A. Di Pasquale; S. Meo; M. Pagano; M. Ribera *"An AHP Approach for the Optimal Sizing of On-Board Energy Storage in DC Rail Transit Systems"* 2024 IEEE International Conference on Artificial Intelligence & Green Energy (ICAIGE24), Hammamet, Tunisy
[C3]	S. Barcellona; M. Ribera; E. Fedele; L. Piegari; L. Codecasa; D. Iannuzzi *"State of Health Estimation of LiCoO2 Cells based on Impulse Response and ARMAX Identification"* 2024 IEEE Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS) and International Transportation Electrification Conference (ESARS-ITEC), Naples, Italy

Thank you for your attention

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