ME 599 – Data Driven Modeling of Dynamical Systems

Comparison of different Data Driven approaches for Li-Ion Battery Modeling

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INTRODUCTION

Data Driven modeling is the approach of analyzing and using data to derive insights about the system and make decisions. It is majorly helpful in predicting the characteristics of a system based on input-output response dataset. Data driven approaches will help us understand the system behavior & characteristics by correlating real time data with past patterns and will allow us to predict accurate insights of the dynamical system. With advances in technology and computing capabilities, the use of a variety of data driven methods can be seen in logistic applications, price prediction, understanding flow behavior , etc.

Hybrid electric vehicles and electric vehicles in general are in increasing demand nowadays. Battery packs are an integral part of such systems. Like many other dynamical systems, the electrochemical reactions occurring inside batteries are governed by multiple high dimensional differential equations. This makes deriving a model of a battery a cumbersome process. The advent of data-driven approaches to modeling dynamical systems comes as a huge relief.

The goal of this project is model discovery of Li-ion battery cells using a gray box modeling approach. We will be using different data driven methods to predict the system characteristics of a Li-Ion battery. This approach is interesting because accurate characteristic estimation and behavior modeling of batteries is crucial for electric vehicles and other applications where batteries are used extensively. A good battery model will help in satisfying multiple requirements of a battery management system like state-of-charge estimation, cell balancing, etc.

As mentioned before, there are many approaches to battery modeling such as Electrochemical modeling (purely physics based), equivalent circuit modeling (thevenin-circuit), analytical and impedance based modeling, empirical and semiempirical modeling.[9] Among these, Equivalent Circuit models are structurally simple and computationally efficient due to the use of lumped-parameter circuit elements, e.g., inductors, resistors, and capacitors, to represent the battery characteristics. So, in this project, we have decided to use equivalent circuit models to provide some intuition on the dynamics of the system and along with data, we have planned to generate a model of the battery.

In the past few decades, a lot of research has been going on battery parameter estimation using gray box modeling approaches. In [3], an estimation method is proposed which relies mostly on the relaxation portion of the battery response and involves some manual calibration. In [3], [8] and [9], system identification techniques are adopted for parameter estimation. [7] uses MathWorks"s Simulink Design Optimization toolbox which implements nonlinear least squares estimation technique and trust-region optimization method to obtain the parameters of the equivalent circuit model.

APPROACH

In this project, we are taking a data set of a Li-ion battery model which is obtained using a Pulse discharge experiment. The experiment involves applying a current discharge pulse for a certain period of time on a cell at regular intervals with a resting period in-between and measuring the cell voltage with a predefined sampling rate. The test is performed from a fully charged to completely drained battery state.

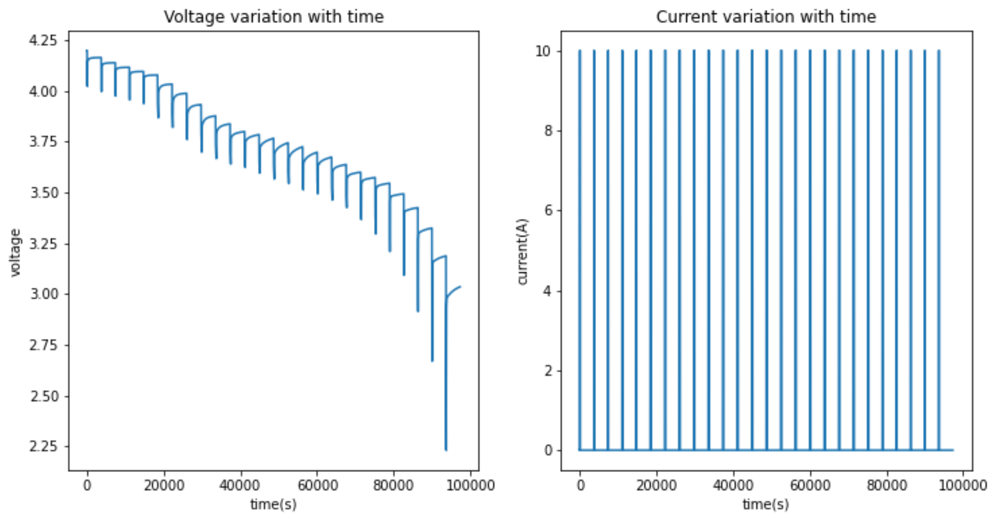

Fig 1: *Pulse Discharge Experiment Dataset*

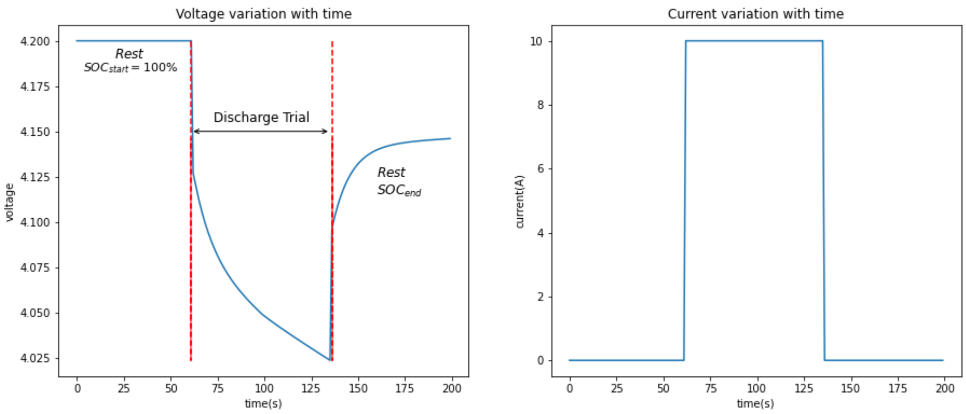

Fig 2: *One Discharge Cycle*

In this experimental dataset, we will apply different data driven methods like Gaussian Process Regression (GPR), Dynamic Mode Decomposition(DMD) and Sparse Identification Of NonLinear Dynamics(SINDy) to find the best fit model of system dynamics (system parameters like Resistance (R) and Capacitance(C)).

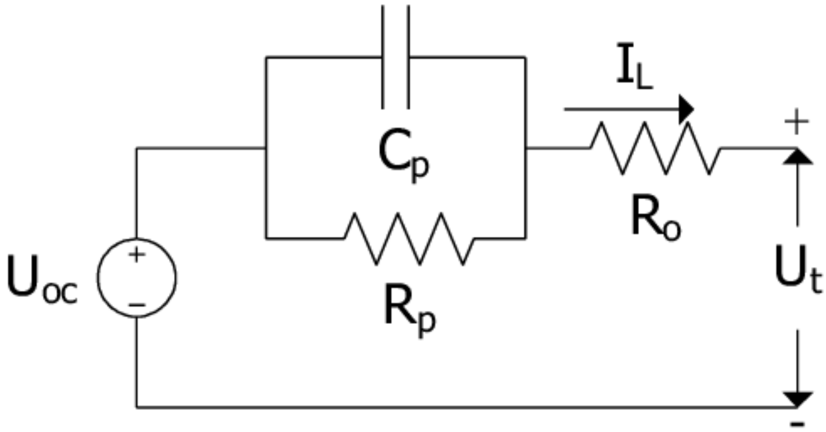

Fig 3: *Common Thevenin's Equivalent circuit of Batteries*[10]

$$U_t = U_{oc} - I_L R_0 - (I_L R_P (1 - e^{(-t/(R_P C_P))}))$$

Where,

- U_{oc} = Open Circuit Voltage
- R_0, R_P = Resistance
- C_P = Capacitance

SINDy helps in finding the unknown dynamics of the system while DMD helps in capturing the temporal dynamics. GPR derives the perfect combination of dynamics of the system. The effectiveness of each of these methods in modeling the system will be comprehensively analyzed and presented. We plan to validate our models with the dataset generated using the System Identification toolbox in Matlab.

For the purpose of this project, we plan to use different softwares, libraries & toolboxes as mentioned below:
Software: Python, MATLAB,
Libraries & Toolboxes: Scikit-learn(Python), NumPy(Python), System Identification Toolbox (MATLAB)

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