Battery Characterization Workshop

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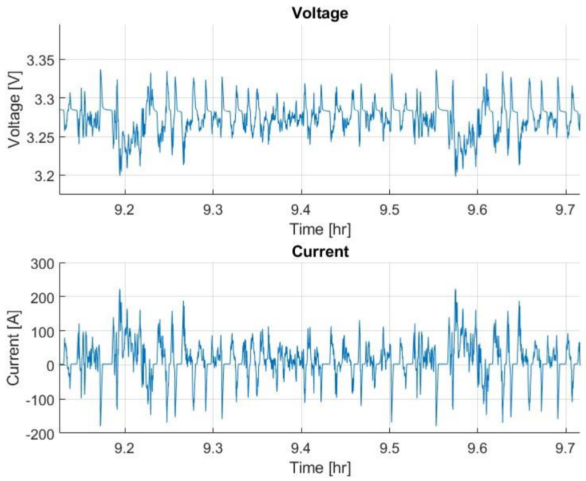
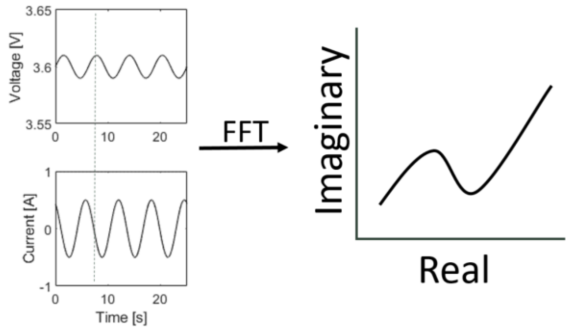
Background

- Battery characterization can be divided into:
  - **Time domain:**
    - Model battery terminal voltage as a function of input current
    - Constant current charge/discharge, pulse, drive cycle tests
    - Model used with model-based adaptive filters for state estimation
  - **Frequency domain:**
    - Electrochemical impedance spectroscopy (EIS)
    - Small amplitude sinusoidal current/voltage applied to cell
    - Use Fourier transform to transform to frequency domain
    - Can be fitted to impedance models to obtain cell information
    - Described in detail in [1]



Example of a time-domain current and voltage profile.

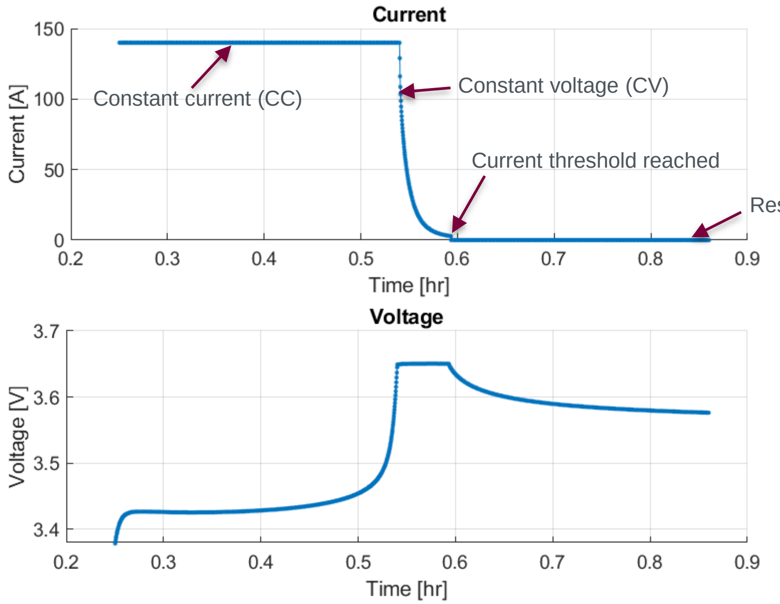


Example of a frequency-domain current and voltage profile [1].

Battery Testing Methods

Charge

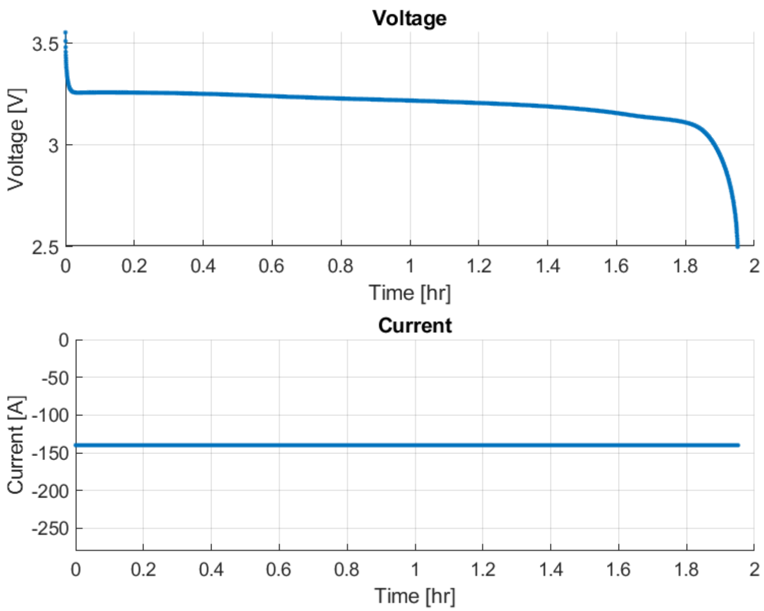
- CC/CV protocol:
  - Charge with constant current until max voltage
  - Maintain voltage and lower current until threshold
- Voltage drops slightly after load is removed
- Current rate and threshold given by manufacturer
- Running analogy



Battery Testing Methods

Capacity Test

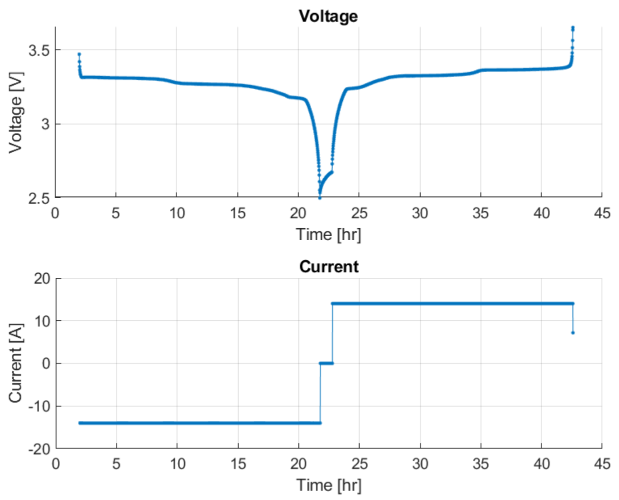
- Cell capacity differs from the nominal value due to manufacturing inconsistencies, calendar aging, cycle aging, etc.
- Constant current discharge until cell reaches minimum voltage
- Capacity can be determined based on current
- Current rate and ambient temperature specified by manufacturer

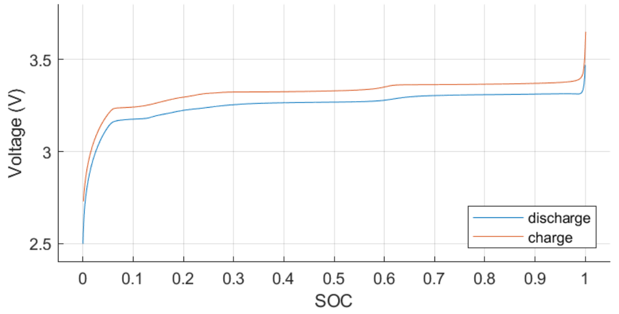


Battery Testing Methods

OCV-SOC Test

- Open-circuit voltage (OCV): Cell voltage when no load is applied
- Has one-to-one relationship with SOC
- Low current (C/20 or less) applied to cell
- Measured terminal voltage is regarded as OCV
- Hysteresis effect: OCV-SOC relationship is slightly different during charge and discharge.
- Hysteresis effect is compensated for in some models [2]





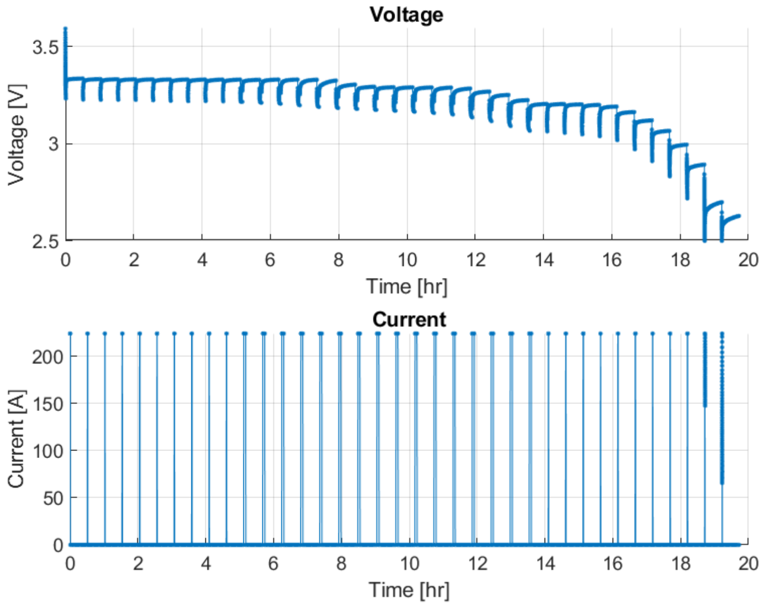
Battery Testing Methods

Pulse Discharge Test

- A series of constant current pulses applied to cell with rests in between
- Duration of the pulses can be calculated by:

$$\Delta t = \frac{(Q * 3600) * \Delta SOC}{I}$$

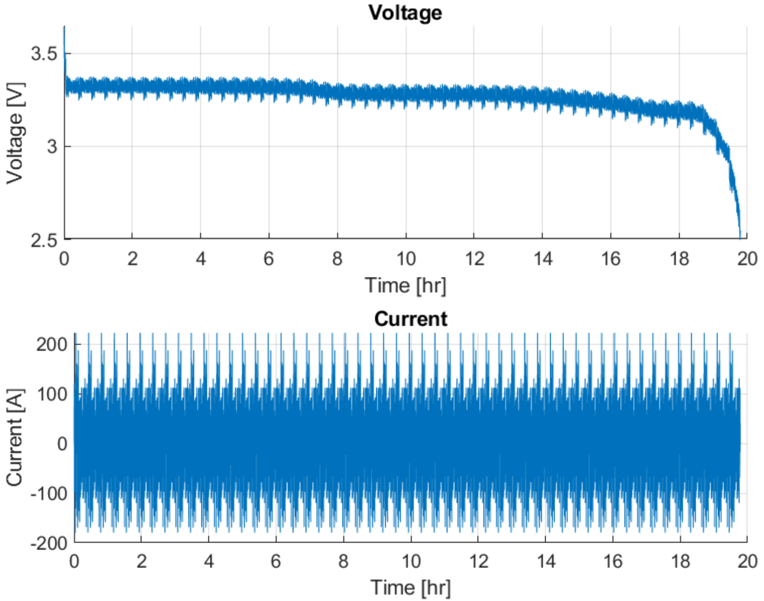
- Current magnitude depends on application
- Rest duration usually between 30 minutes to 2 hours although other lengths have been used [3]
- Used to obtain cell characteristics at each SOC



Battery Testing Methods

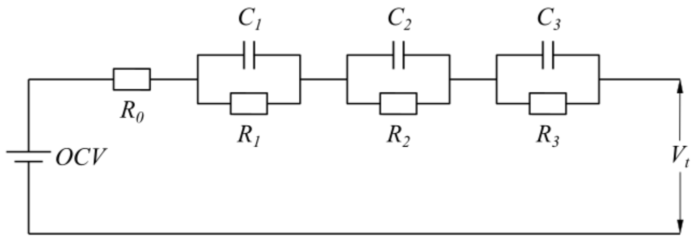
Drive Cycle Test

- Dynamic tests with realistic current demands
- Provided in speed vs. time format at [4]
- Converted to current demand using a vehicle model, scaled down to cell-level based on pack configuration
- Cycle repeated until cell reaches minimum voltage
- Can be used for parameter identification and validation
- Common drive cycles:
  - UDDS: normal city driving
  - US06: aggressive driving
  - HWFET: highway driving



Parameter Identification

Equivalent-Circuit Model



- Represent internal processes with circuit elements
  - Ideal voltage source: OCV
  - Series resistance: ohmic resistance
  - RC branches: different internal processes with different time constants
- Provide good compromise between accuracy and complexity [5]
- Terminal voltage:

$$v_{[k]} = OCV_{(z_k)} - R_0 i_{[k]} - R_1 i_{1[k]} - R_2 i_{2[k]} - R_3 i_{3[k]}$$

- Current through each RC branch:

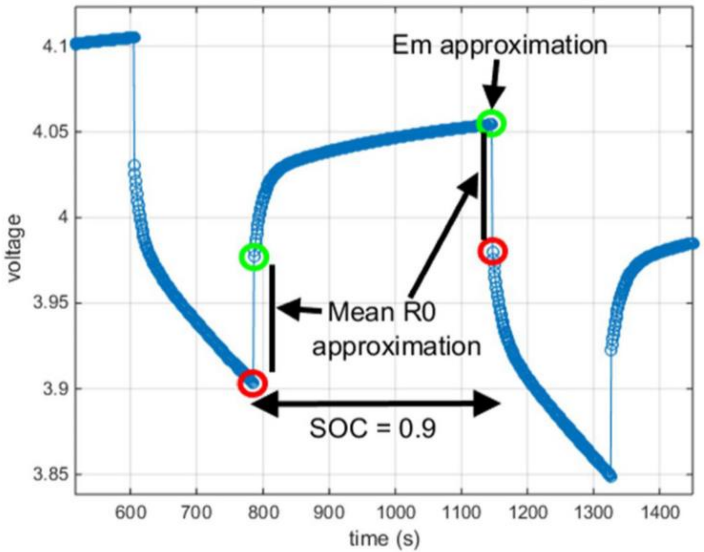
$$i_{i\,[k+1]} = exp(-\frac{\Delta t}{R_i C_i}) * i_{i\,[k]} + (1 - exp(-\frac{\Delta t}{R_i C_i})) * i_{[k]}$$

- Time constants, $\tau_i = R_i C_i$, should be sufficiently apart

Parameter Identification

Optimization Procedure

- Optimization algorithms are used to fit the model to data
- Objective function: mean squared error (MSE) between simulated and measured terminal voltage
- Divide data by SOC to obtain a parameter look-up table
- Initial conditions and upper/lower bounds usually found through trial and error
- [6] proposed a method to set the initial values based on knowledge about the circuit

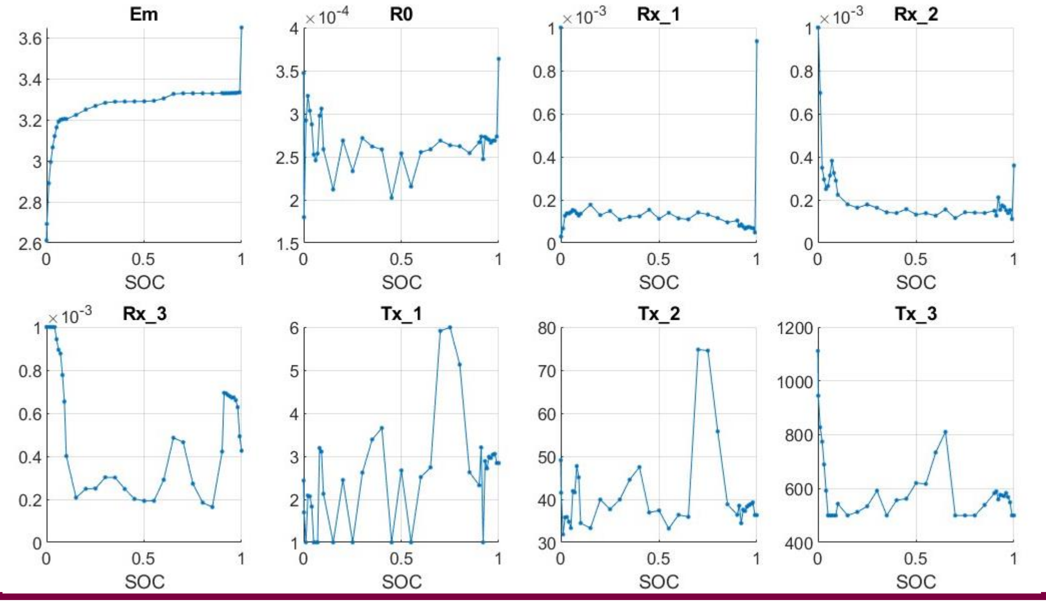


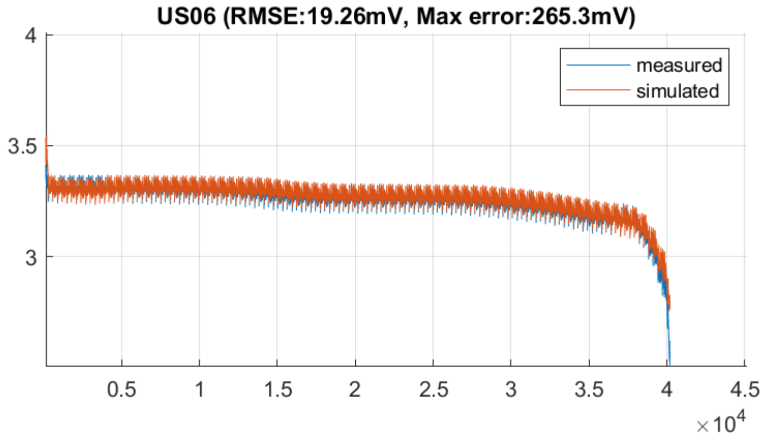
Approximating ohmic resistance and OCV [6]

Parameter Identification

Example

- Parameters obtained from pulse discharge test using method proposed in [6]
  - Current: 0.8 C
  - Rest: 30 minutes





Accompanying Data and Scripts

Data

- Battery: EVE 280 LFP (data sheet attached)
- Temperature: 25 °C
- Test data:
  - Standard charge
  - OCV-SOC test
  - Pulse discharge tests @ 0.8C (1, 5, 15, 30, 60 minutes rest)
  - Pulse discharge test @ 0.1C with 60 minutes rest
  - Drive cycle tests
    - UDDS, US06, HWFET, NEDC, MIX
    - Maximum current of 0.8C

Accompanying Data and Scripts

Scripts

- Scripts to parameterize a 1st, 2nd or 3rd order ECM using two methods:
  - Direct method
  - Analytical method [6]
- Script to run an nth order ECM to validate parameters identified

Filename	Description
parameterization_direct.m	Parameterizes the ECM using the direct method.
parameterization_analytical.m	Parameterizes the ECM using the semi-analytical method.
batterymodel_run.m	Runs the battery model to validate the input parameters.
ecm.m	Function that calculates the battery terminal voltage with a given set of parameters and current input.
format_opt_param.m	Function that manipulates the format of the model parameters for use with different scripts.
parameter_initialization.m	Function that sets the initial conditions and the bounds for optimization.
parameterization_Objective.m	Function that calculates the value of the objective functions.
parameterization_Optimize.m	Function that sets the optimization method and optimization parameters.

Conclusion

- Battery characterization divided into **time-domain** and frequency domain techniques
- Battery testing methods:
  - Charge, capacity, OCV-SOC, pulse discharge, drive cycle
- Parameter identification
  - Equivalent-circuit model: Use RC branches to represent different internal processes
  - Optimization algorithm to fit model to parameter
  - Divide data into segments by SOC to obtain parameter look-up table
- Accompanying Data and Scripts

References

[1] M. Messing, “Case Study: EIS Model Fitting and Analysis – HEVPD&D-CREATE,” Aug. 2019. http://hevpdd.ca/publications-and-case-studies/eis-model-fitting-and-analysis/ (accessed Oct. 24, 2022).

[2] G. Plett, Battery Management Systems, Volume I: Battery Modeling. Norwood, UNITED STATES: Artech House, 2015. Accessed: Oct. 24, 2022. [Online]. Available: http://ebookcentral.proquest.com/lib/mcmu/detail.action?docID=4821261

[3] W. Zhang, R. Ahmed, and S. Habibi, “The Effects of Test Profile on Lithium-ion Battery Equivalent-Circuit Model Parameterization Accuracy,” in 2022 IEEE Transportation Electrification Conference & Expo (ITEC), Jun. 2022, pp. 119–124. doi: 10.1109/ITEC53557.2022.9814019.

[4] US Environmental Protection Agency, “Dynamometer Drive Schedules,” Sep. 16, 2015. https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules (accessed Dec. 10, 2021).

[5] X. Hu, S. Li, and H. Peng, “A comparative study of equivalent circuit models for Li-ion batteries,” Journal of Power Sources, vol. 198, pp. 359–367, Jan. 2012, doi: 10.1016/j.jpowsour.2011.10.013.

[6] R. Ahmed et al., “Model-Based Parameter Identification of Healthy and Aged Li-ion Batteries for Electric Vehicle Applications,” SAE International Journal of Alternative Powertrains, vol. 4, no. 2, pp. 233–247, 2015.

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