Stanford | SCHOOL OF EARTH, ENERGY & ENVIRONMENTAL SCIENCES

Homework 3 (90 points)

ENERGY 294 - Electrochemical Energy Storage Systems: Modeling and Estimation

Spring Quarter 2018

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Due May 18, 2018 at 12 PM (Electronic pdf copy in CANVAS and hard-copy to the TA)

Data from the electrochemical impedance spectroscopy (EIS) machine have been collected to measure battery impedance at different AC frequencies.

The EIS machine applies a programmable constant current load and also a small programmable sinusoidal load to the battery simultaneously. This sinusoidal (or AC) load can have a range of frequencies. The EIS machine performs a sweep of frequencies defined by the user. At each frequency, the machine calculates the impedance of the battery by comparing the battery's AC current response to the machine's AC current demand. A **Nyquist impedance plot** and **Bode plot** are displayed using the EIS computer software. This software also allows users to **fit** their **data to an equivalent circuit model.**

The EIS test was run for a lithium-ion cell of the type:

Manufacturer	Sony
Model	VTC4
Cathode Chemistry	Lithium Nickel Manganese Cobalt Oxide (NMC)
Form Factor	18650
Capacity (Nominal)	2100 mAh
Maximum Voltage	4.2 V
Cutoff Voltage	2.5 V

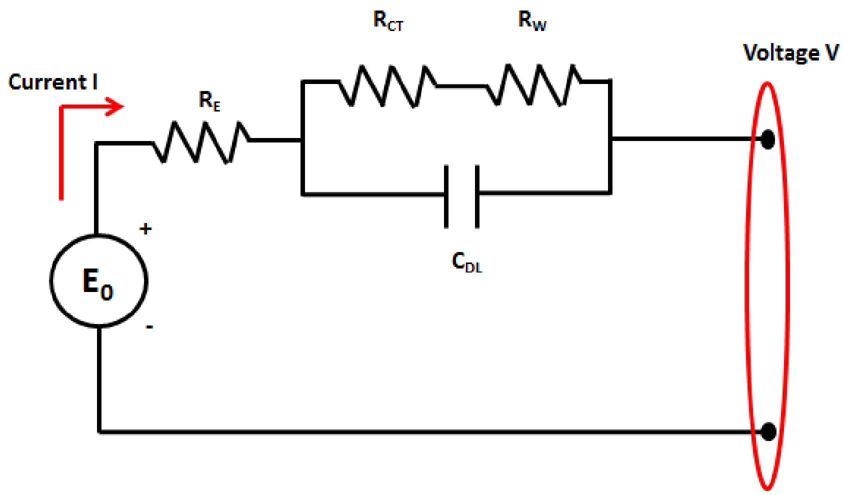
over the range of frequency of [0.001 Hz-10000 Hz].

You are given the following set of EIS data (acquired at 23°C):

- JCI_Cell_5_AHS_AgingCycle1_06012016.xlsx
- JCI_Cell_5_AHS_AgingCycle2_07012016.xlsx
- JCI_Cell_5_AHS_AgingCycle3_08102016.xlsx

The cell named #5 was aged according to a specific aging cycle (referred to as **Aggressive and High Speed – AHS) at 45°C (see Lecture 6)**

Using these data sets, you must correlate the information provided with the Randles equivalent circuit shown below.



where R_E is the resistance due to the battery electrolyte, R_{CT} is the resistance due to charge transfer, and R_W is the Warburg resistance due to diffusion within the battery. C_{DL} is the double layer capacitance due to the anionic and cationic charge regions that form in the electrolyte next to the battery electrodes.

The aim of this homework is to understand the different states of health of the cell #5 through model parameter identification from EIS data collection. Perform the following tasks:

1. Report the Nyquist and Bode plots for the data analyzed for battery cell #5 ~~and fitted equivalent circuit parameters based on the data sets provided.~~
2. Graphically show which portions of the Nyquist plots represent the parameters R_E, R_{CT}, C_{DL}, and R_W. With respect to the Nyquist plots, describe the contributions of R_E, R_{CT}, C_{DL}, and R_W elements at different frequencies.
3. Illustrate/Explain the difference in the parameters over the different aging stages.

Problem 2

In this part of the homework assignment, you will use EIS test data to identify the parameters R_0, R_1, and C_1 of a first-order equivalent circuit model (ECM). Note that the EIS test is conducted at a battery state-of-charge (SoC) where the relationship between the open circuit voltage, V_{oc}, and SoC is affine. The voltage of the cell at the beginning of the EIS test is indicated in the column under "Bias" in the data sheets provided. Also note that I is the input current and V is the output voltage response of the model. Perform the following tasks:

a) Using the "LowInitialCapTest1" data set provided, determine the nominal capacity of the battery, Q_{nom}, and the parameters α and β for the relationship:

$$V_{oc}(SoC) = \alpha \cdot SoC + \beta$$

b) From the equations that describe the dynamics of a first order ECM, determine the expression of the impedance $Z(s)$, which is given by:

$$Z(s) = \frac{V(s)}{I(s)}$$

c) Using $Z(s)$ comment whether or not you can identify the 3 parameters of the first-order ECM using the EIS data for "AgingCycle1" over the entire frequency range of the data set. Attempt to identify the best set of parameter values within the frequency range 0.001 Hz to 50 Hz.

d) To achieve this, formulate a cost function that minimizes the root mean square (RMS) error between the experimental and model-predicted magnitude as well as phase values (based on the transfer function expression of $Z(s)$). Use the *ga* algorithm for parameter identification. Based on the midterm, make an educated decision on the initial guess for the first-order ECM parameters. Use your best judgement on the upper and lower bounds during the identification process.

e) Report the % RMS error for the magnitude variation, and the % RMS error for the phase variation. Use a mathematical formulation of the RMS error similar to the one provided in the midterm.

f) Repeat the identification study for the "AgingCycle2" and "AgingCycle3" data sets. Tabulate the values of the parameters R_0, R_1, and C_1, and the % RMS errors for both magnitude and phase for all the identification studies.

g) Based on the three identification study results, provide the plots between the experimental and model predicted magnitude variation, and the experimental and model predicted phase variation of the cell impedance.

h) Comment on the results observed.