Homework 2 (120 points)

ENERGY 295 - Electrochemical Energy Storage Systems: Modeling and Estimation

Fall Quarter 2021

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Due October 15, 2021 at 11 AM (Electronic pdf copy in CANVAS)

Please, include your MATLAB code in the final submission

This assignment is aimed at testing your understanding of battery terminology learnt in class so far.

Problem 1 (30 points) (this was Problem 3 in HW 1)
For the following dynamical system

$$\frac{d^2x(t)}{dt^2} + \frac{dx(t)}{dt} + x(t) - u(t) = 0$$

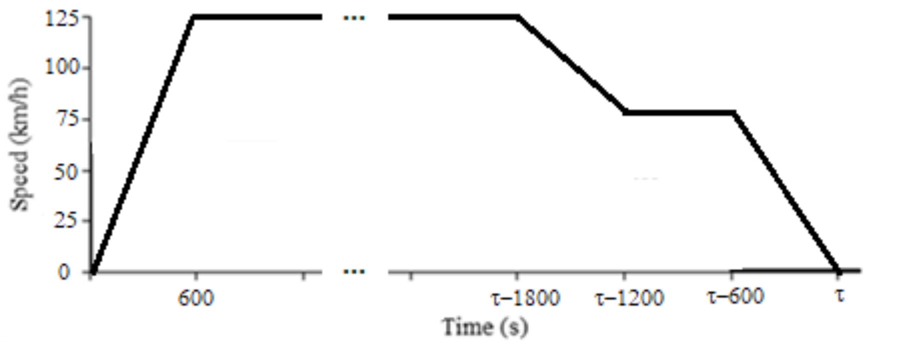
We know that the initial conditions are $(x(0) = 0,\ \dot{x}(0) = 0)$. The forcing input $u(t)$ is a step input of magnitude 2. Assume that the value of $x(t)$ is available via a sensor.

In HW 1, you have 1) derived the state space model, and 2) studied the observability of the system.

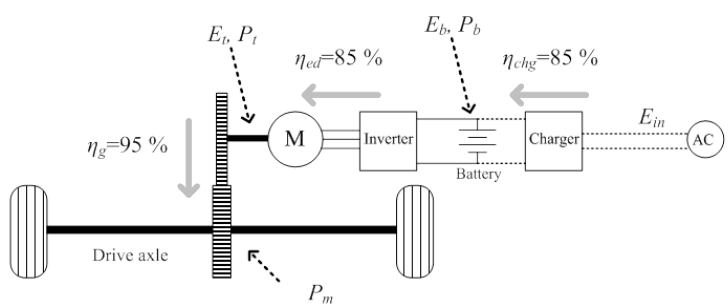
Now, we want to design a closed-loop estimator.

1) Write the closed-loop estimator equations and determine the observer gains (you have to make the choice on where to place the estimator eigenvalues)
2) Simulate both observers in Matlab. In particular, for the following sets of observer initial conditions (-1, -3), (-6, -10) and (-10, -15), plot the state estimation results against the true values of states.
3) Plot the errors dynamics when the estimator starts from the same set of initial conditions in 2).

Problem 2 (40 points)
You are driving an EV according to the drive cycle shown below:



You are concerned about the range of your vehicle and are trying to calculate how far you can travel before stopping to recharge.
The EV has the following powertrain:



and vehicle parameters:

M_{veh}	c_{roll}	C_D	A_f	ρ_{air}	E_b
1645kg	0.0083	0.28	2.92m^2	1.2 kg/m^3	40kWh

1. Assuming you are driving on a flat road, determine the traction power for each of the five sections of the drive cycle as a function of t and τ. **Note**: You will probably want to use wolfram alpha or Matlab symbolic for the symbolic calculation
2. Convert traction power to energy required from the battery by applying transmission efficiencies and integrating from 0 to τ with respect to t. Your answer should still be in terms of τ. **Note:** The integration limits of the piecewise power function may require extra attention
3. Set the energy equation obtained in 2. equal to the nominal battery energy E_b and solve for τ. How much time was spent on the highway? What is the total distance traveled, i.e. the range of the vehicle for this drive cycle?
4. Calculate the MPGe and the CO_2 emissions assuming the CA state average of 238 gCO_2/kWh.

Problem 3 (50 points)

You are given data from experiments conducted on a 2170 cylindrical lithium-ion cell at temperatures $T = 25°\text{C}$ and five C-rates of operation: $[0.05,\ 1,\ 2,\ 3,\ 5]$. The technical specifications of the cylindrical lithium-ion cell are tabulated below [1]:

Battery Name	INR21700 M50	
Manufacturer	LG Chem	
Rated Capacity	5Ah	
Nominal Voltage	3.63V	
Maximum Voltage	4.2V	
Minimum Voltage	2.5V	
Cathode Chemistry	NMC	
Anode Chemistry	Graphite	
Cell weight	68 g	

Table 1: Experimental data summary at temperature of 25°C for a lithium-ion cell

Excel filename	**Data Set description**	**Initial SOC**	**Sampling Time**
NMC_T25_0_05C_CTID.xlsx	0.05 C-rate Capacity Test In Discharge (CTID)	100%	1sec
NMC_T25_1C_CTID.xlsx	1 C-rate Discharge Test	100%	1sec
NMC_T25_2C_CTID.xlsx	2 C-rate Discharge Test	100%	1sec
NMC_T25_3C_CTID.xlsx	3 C-rate Discharge Test	100%	1sec
NMC_T25_5C_CTID.xlsx	5 C-rate Discharge Test	100%	1sec

The nomenclature for the file names is NMC_T$$_##C_CTID.xlsx

$$ = [25°C]

= [0.05, 1, 2, 3, 5] C-rate.

Import the data from the excel sheets to MATLAB. You may use "xlsread" or "importdata" commands. You are requested to perform the following tasks using MATLAB:

1. Determine the discharge capacity for each C-rate provided. Report your calculations and tabulate these values.
2. Provide a 2-D plot of cell capacity Q vs. C-rate at temperature T.

3. For the whole data set at temperatures T, plot cell voltage as a function of discharge capacity (the plot would contain 5 voltage curves corresponding to the different C-rates).
4. Plot State of Charge as a function of time for the whole data set (the plot would contain 5 SoC curves corresponding to the different C-rates).
5. Calculate the specific energy and specific power of the battery cell and report the results:
   a) in a tabular format;
   b) on the Ragone plot. Remember, the Ragone plot is in logarithmic scale on both axes.

Hint for 5.

Specific Energy [Wh/kg]: $\frac{\text{Energy calculated during the discharge}}{\text{battery cell mass}}$

Specific Power [W/kg]: $\frac{\text{Specific Energy}}{\text{time taken for the battery to discharge}}$

Note: All the experiments are conducted using an Arbin BT-2000 tester, for which the current convention is positive during charge and negative during discharge and the sampling time is 1 sec.

Reference

[1] Catenaro, E., Rizzo, D., Onori, S., "Experimental Analysis and Analytical Modeling of Enhanced-Ragone Plot", Applied Energy Vol. 291, 2021