Exam
TSFS19 Battery Systems

Date	2024-12-18
Location	
Time	08-12
Course Code	TSFS19
Course Name	Battery Systems
Exam Code	TEN1
Number of Questions	5
Course Responsible	Mattias Krysander
Instructor Visiting Exam Room	Mattias Krysander
Phone During Exam	073-270 18 25
Visits Exam Room	Around 09 and 11
Course Administrator	Karin Blomdahl, TEL
Allowed Aids	Ruler, calculator, formula sheet
Preliminary Grade Boundaries	Points Grade 33-40 5 25-32 4 17-24 3 0-16 U
Review	XX:XX-YY:YY on DD/MM in Mattias Krysander's office at ISY/DA

Good luck with the exam!

Task 1. Mixed battery questions.

a) Consider a rechargeable nickel-cadmium battery with the following helf-cell reactions

$$\mathrm{Cd(OH)_2(s) + 2e^- \rightarrow Cd(s) + 2OH^-(aq)} \quad V^\circ = -0.83\,\mathrm{V}$$

and

$$\mathrm{NiO(OH)(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)} \quad V^\circ = 0.52\,\mathrm{V}$$

Write the balanced full-cell reaction for **discharge** and compute the standard cell potential. (2 points)

b) Draw a picture of a nickel-cadmium battery discharged over a resistance. The drawing should contain and point out positive and negative electrodes, electrolytes, and the movement of all charged particles creating a current through the resistance. (3 points)

c) Mention 3 different types of abuse of li-ion batteries that can result in a battery fire and thermal runaway. (1 points)

d) Mention 2 different principles of estimating SOC in a battery and write done the corresponding formulas. (2 points)

Solution.

a) The full-cell reaction is:

$$\mathrm{Cd(s) + 2NiO(OH)(s) + 2H_2O(l) \rightarrow Cd(OH)_2(s) + 2Ni(OH)_2(s)}$$

The standard cell potential is $V^\circ = 0.52 - (-0.83) = 1.35$ V.

b) See page 19 lecture 1.

c) Overcharging, short-circuiting, and overheating.

d) SOC can be estimated by Coloumb counting integrating measured the current $i(t)$

$$\mathrm{SOC}(t) = \mathrm{SOC}(t_0) + \frac{100}{Q}\int_{t_0}^{t} i(t)dt$$

or estimation using measured voltage $v(t)$ based on the open circuit voltage dependance of SOC (ocv = f(SOC)).

$$\mathrm{SOC}(t) = f^{-1}(v(t))$$

Task 2. Consider a battery with two series-connected cells with the following properties:

Cell 1: $Q_1 = 3$ Ah, $\mathrm{SOC}_1 = 40$ %, $V_{\mathrm{nom}} = 3.5\,\mathrm{V}$.

Cell 2: $Q_2 = 4$ Ah, $\mathrm{SOC}_2 = 20$ %, $V_{\mathrm{nom}} = 3.5\,\mathrm{V}$.

a) What is the charge capacity of the battery without cell balancing? (2 points)

b) Assume that the battery has passive balancing. The balancing SOC set-point should be 50 %. Which cell should be discharged to reach the balancing SOC set-point? How much charge should be discharged with the balancing circuit? What is the charge and energy capacity of the balanced battery? Hint: Assume that the cell voltage is independent of the SOC. (4 points)

c) Assume that the cells are connected in parallel instead. What is the energy capacity of the parallel connected battery? (1 points)

Solution.

a) The charge capacity is 2.60 Ah

b) Cell 1 should be discharged with: 0.90 Ah.
The total charge capacity is: 3.0 Ah
The total energy capacity is: 21.0 Wh

c) The total energy capacity is 24.5 Wh.

Task 3. Two tests have been performed on a new cell. One test is a discharge charge cycle and the other is a current step of 1 A. The measurement data can be seen in Figures 1 and 2 respectively. Answer the following questions based on the data and motivate how the data is used to answer the questions.

a) What is the charge capacity of the cell? (1 points)

b) What is the OCV at 50 % SOC? Answer with two decimal digits. (2 points)

c) Model the cell impedance with a Thevenin equivalent circuit including a resistance and an RC-link. What are the parameter values? (3 points)

Solution.

a) The estimated charge capacity is 9.71 ± 0.05 Ah.

b) The OCV at 50 % SOC is 3.70 ± 0.01 V.

c) The impedance parameters are: $R_i = 20$ mΩ $R = 10$ mΩ, and $C = 5.0$ kF.

Task 4. An electric vehicle has a battery pack consisting of 36 modules in series. Each module has 3 cells in series and 4 in parallel. The cells have a charge capacity of 60 Ah, internal resistance 3 mΩ, the minimum cut-off voltage at 2.75 V. The cells are used within a limited SOC window, which is unknown to the user. The SOC displayed to the user ranges from 0 % to 100 %, and it is this user-represented SOC that will be used in this context. The relationship between SOC display to the user and Open Circuit Voltage (OCV) is defined by the following table:

SOC (%)	OCV (V)
0	3.34
10	3.53
60	3.75
100	4.12

a) Compute the nominal cell voltage and total cell energy within the specified operating range at a 1C discharge rate. **Hint:** The nominal cell voltage is the average voltage during a discharge at a constant current of 1C, from 100 % to 0 % SOC. Note that the current does not need to be reduced as the SOC approaches 0 %, because within the limited SOC window, the terminal voltage remains above the minimum cut-off voltage. (3 points)

b) Compute the following pack properties: nominal voltage, charge capacity, and energy capacity. (3 points)

c) The car is designed to handle a maximum battery power output of 300 kW for short durations. What is the internal resistance of the battery pack? What is the maximum current from the battery? What is the minimum SOC at which the battery can deliver its maximum power output? (3 points)

Solution.

a) Cell characteriztics:
Nominal voltage: 3.56 V
Cell energy: 213.45 Wh

b) Pack characteriztics:
Nominal voltage: 384.21 V
Charge capacity: 240 Ah
Energy capacity 92.2 kWh

c) Pack resistance: 81.0 mΩ
Max pack currnet: 1010 A
Min SOC for delivering max power: 8.8 %

Task 5. Consider a sodium-ion battery with the following properties, Q = 1.5 Ah, R = 30 mΩ, $V_{\max} = 3.95\,\mathrm{V}$, and an OCV function defined as

$$\mathrm{OCV} = 2.3 + 1.65\frac{\mathrm{SOC}}{100}$$

The battery is charged with a constant current (CC) of 1C until $V_{\max}$ is reached. The battery is then charged with a constant voltage (CV) $V_{\max}$ until the current drops to C/50.

a) Compute the following properties of the CC-charging phase:
   - Charging current expressed in Amperes,
   - OCV and SOC at the end of the CC phase, and
   - the time of the CC phase. (4 points)

b) Compute the following properties of the CV charging phase:
   - Cut-off current expressed in Amperes,
   - SOC at the end of the CV phase, and
   - the total amount of charge added during the complete CCCV charging. (3 points)

c) Considering a 1C charge discharge cycle in a 20 to 80% SOC window. What is the energy required to charge the cell in this SOC window? What is the output energy discharging the cell in the same SOC window at 1C? What is the energy efficiency of the cell for this charge discharge cycle? (3 points)

Solution.

a) Constant current charging characteriztics:
   CC current: 1.50 A
   OCV at end of CC: 3.91 V
   SOC at end of CC: 97.27 %
   Time charging in CC-mode: 0.97 h = 58 min 22 s

b) Constant voltage charging characteriztics:
   CC cut-off: 0.03 A
   SOC at end of CV: 99.95 %
   Total charge: 1.499 Ah

c) The charge energy is 2.85 Wh
   The discharge energy is 2.77 Wh
   The cycle energy efficiency is 97.2 %

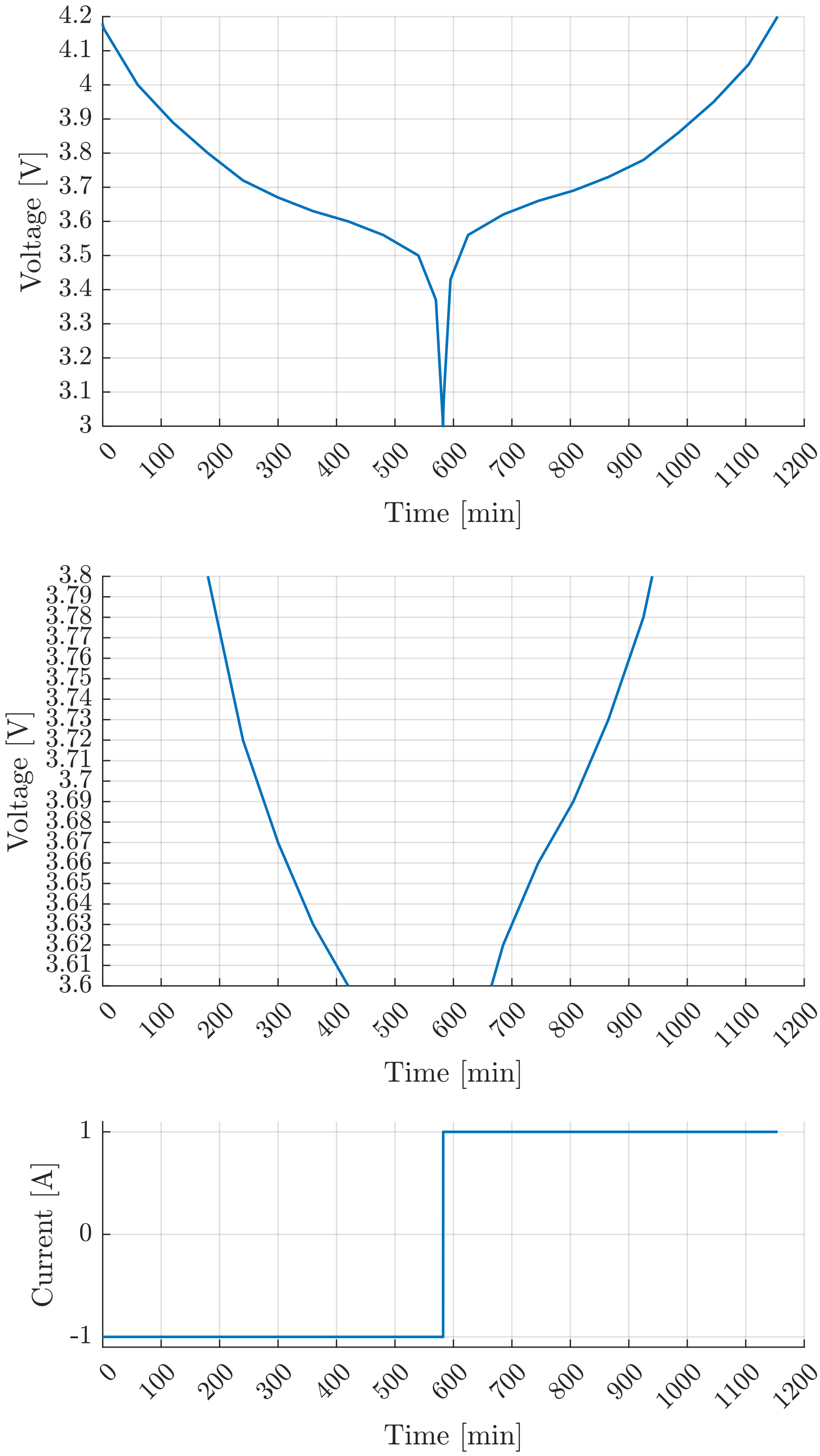

Figure 1: Measured voltage and current during a discharge-charge cycle of a battery.

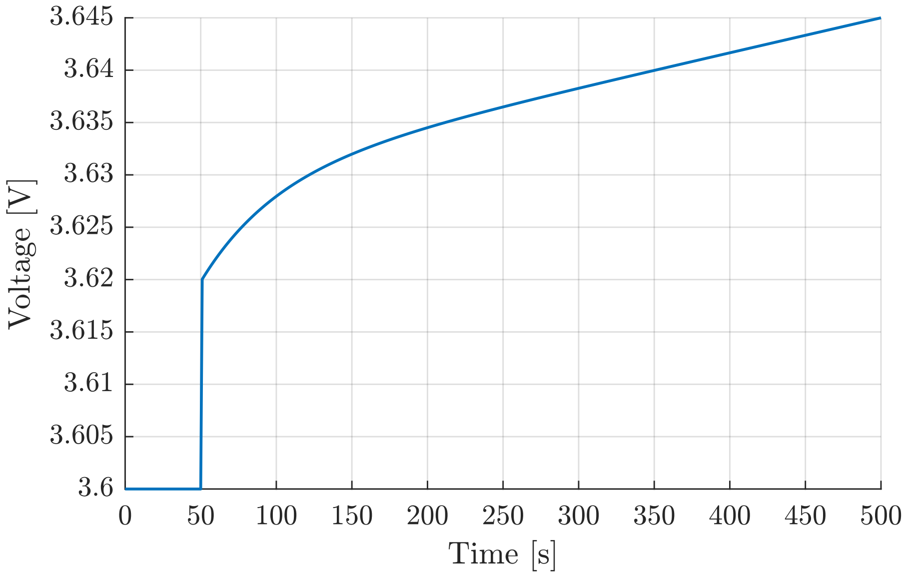

Figure 2: Measured voltage response for a 1 A current step.