University of Windsor
Dept. of Electrical & Computer Engineering

Advanced Energy Storage Systems
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Project-2: Battery Fuel Gauge

The goal in this project is to implement a battery fuel gauge that continuously estimates the state of charge (SOC) and time to shut down (TTS) of the battery.

Coulomb Counting Approach

You will use the Coulomb counting approach to estimate the SOC. The Coulomb counting is achieved recursively through the following equation

$$s(k) = s(k-1) + \frac{\Delta i(k)}{Q} \tag{1}$$

where $s(k)$ is the SOC at the present time instant k, Q is the battery capacity in Ampere hours (Ah), Δ is the sampling time in hours, and, $i(k)$ is the current at the present time instant k in Amperes.

TTS Estimation Approach

TTS is the time it would take until the terminal voltage reaches $\mathrm{OCV}_{\mathrm{min}}$. Follow the steps below for TTS estimation:

1. Let us denote the target terminal voltage as $v_{\mathrm{t}} = \mathrm{OCV}_{\mathrm{min}}$.
2. Compute the voltage drop $v_{\mathrm{d}} = i_{\mathrm{L}} R_0$, where i_{L} is the load current. For this project, it is given that $i_{\mathrm{L}} = -200\mathrm{mA}$.
3. Compute target OCV
$$V_{\mathrm{ot}} = v_{\mathrm{t}} - v_{\mathrm{d}} = \mathrm{OCV}_{\mathrm{min}} - v_{\mathrm{d}} > \mathrm{OCV}_{\mathrm{min}} \tag{2}$$
4. Compute target SOC using SOC lookup method
$$s_{\mathrm{t}} = f_{\mathrm{o}}^{-1}(V_{\mathrm{ot}}) \tag{3}$$
5. Compute SOC difference. Here, $s(k)$ is the SOC computed using the CC approach (1)
$$s_{\mathrm{d}}(k) = s(k) - s_{\mathrm{t}} \tag{4}$$
6. Compute TTS at time k as
$$\mathrm{TTS}(k) = \frac{s_{\mathrm{d}}(k) Q}{|i_{\mathrm{L}}|} \tag{5}$$

The following two datasets are provided. Both data belong to the same battery.

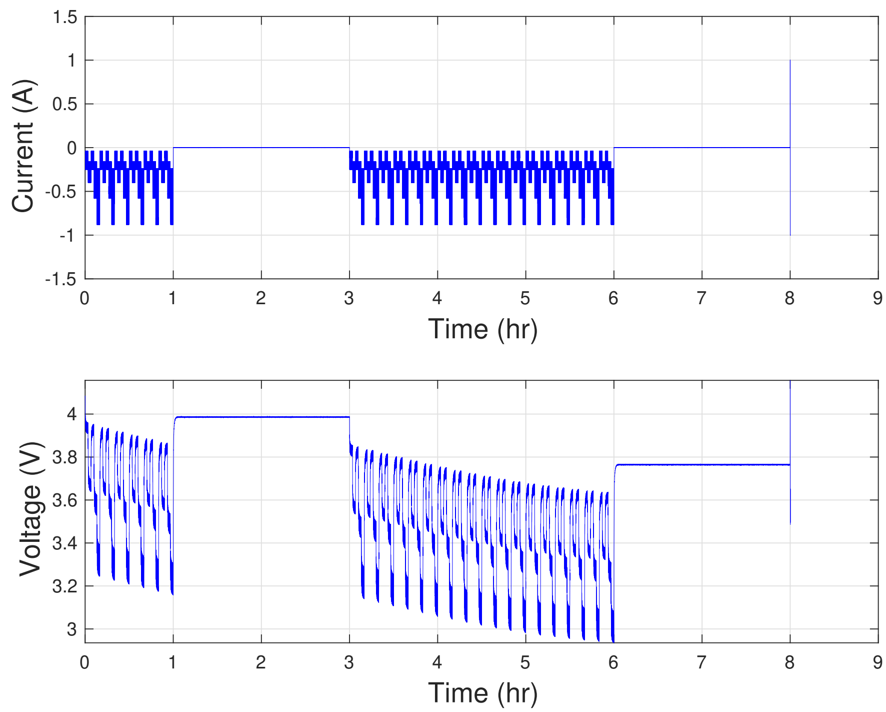


Figure 1: TIVdata1.mat (Use this data to estimate battery capacity Q and internal resistance R_0.)

TIVdata1 You will use the time, voltage and current data (shown in Figure 1) from the matlab data file named 'TIVdata1.mat' to accurately estimate the **capacity** (Q) and the **internal resistance**(R_0) of the battery. Table 1 shows the first seven data points from 'TIVdata1.mat'.

TIVdata2 You will use the time and current data (shown in Figure 2) from the matlab data file named 'TIVdata2.mat' to implement a battery fuel gauge (BFG).

Table 2 shows the first seven data points from 'TIVdata2.mat'.

Table 1: TIVdata1.mat (First seven data points are shown)

Time (hr)	Current (A)	Voltage (V)
2.7777e-05	-0.0393	4.0840
5.5555e-05	-0.0402	4.0845
8.3333e-05	-0.1203	4.0619
1.1111e-04	-0.1195	4.0626
1.3889e-04	-0.0401	4.0773
1.6667e-04	-0.0394	4.0750
1.9444e-04	-0.0396	4.0752
⋮	⋮	⋮

The Algorithm 1 explains the steps involved in the BFG to be implemented in this project. You will complete the BFG design by answering Questions 1 to Question 5.

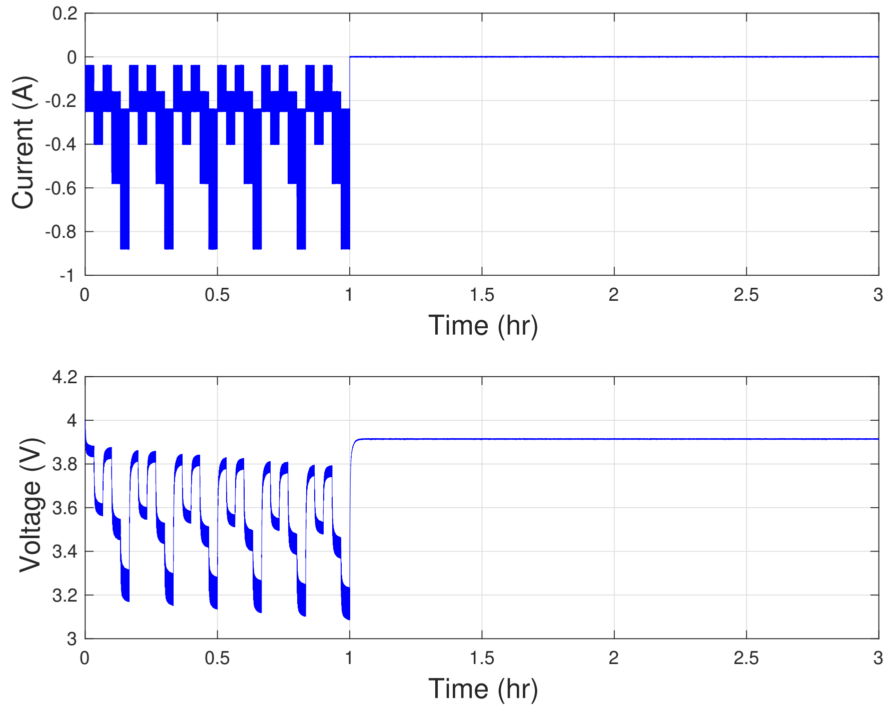


Figure 2: TIVdata2.mat (Use this data for SOC and TTS estimation)

Table 2: TIVdata2.mat (First seven data points are shown)

Time (hr)	Current (A)	Voltage (V)
2.7777e-05	-0.0412	4.0059
5.5555e-05	-0.0404	4.0046
8.3333e-05	-0.1203	3.9880
1.1111e-04	-0.1213	3.9846
1.3889e-04	-0.0384	3.9992
1.6667e-04	-0.0388	3.9988
1.9444e-04	-0.0399	3.9976
⋮	⋮	⋮

Algorithm 1 Battery Fuel Gauge (BFG)

Compute battery capacity Q (see Question 2)
Compute battery internal resistance R_0 (see Question 3)
Compute initial SOC $s(1)$ (see Question 4)
for $k = 2, 3, 4, \ldots L$ **do** ▷ where $L = 108,000$ is the number of data points
    Compute SOC $s(k)$ using (1)
    Compute time to shut down TTS(k) using (5)
end for

Question 1 (SOC lookup)

Based on the data given in the file named 'TIVdata1.mat' (and shown in Figure 1) and the OCV parameters corresponding to the Combined+3 model in Table 3, compute the SOC of the battery at the following two points:

- At $t_1 = 2$ hours (denote the SOC at this time as s_1)
- At $t_2 = 7$ hours (denote the SOC at this time as s_2)

Hint: Use the bisection method or any other root finding method.

Table 3: OCV Parameters (use with scaling factor $\epsilon = 0.175$)

Parameter	Value
k_1	-9.082
k_2	103.087
k_3	-18.185
k_4	2.062
k_5	-0.102
k_6	-76.604
k_7	141.199
k_8	-1.117

Question 2 (Battery capacity estimation)

- Based on the references provided in Question 1, compute the Coulomb difference between time t_1 and time t_2. You may use the following formula to compute these Coulombs:

$$d_c = C = \int_{t_1}^{t_2} i(t)\ dt \tag{6}$$

$$= \sum_{k=1}^{N} i(k)\Delta_k \tag{7}$$

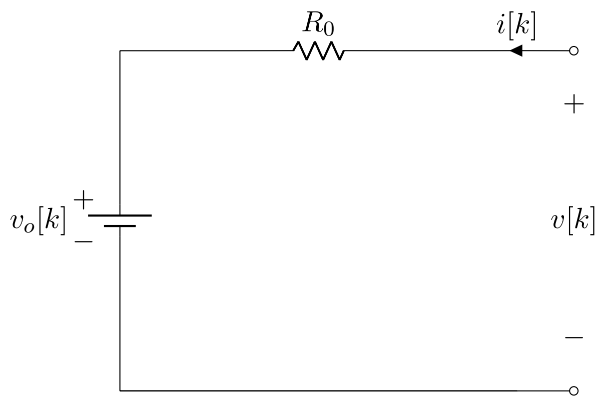
  where $i(t)$ is the current at time t.

- Compute the battery capacity Q

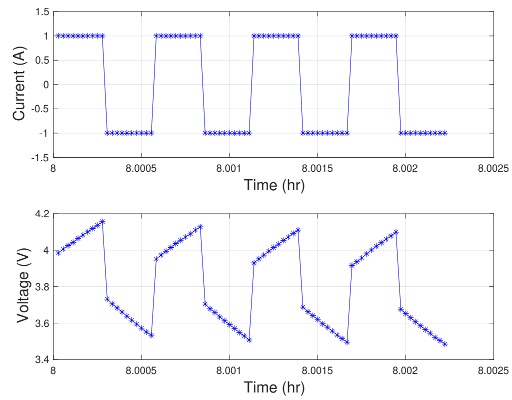
Question 3 (Resistance estimation)

You will use the equivalent circuit model (ECM) of the battery shown in Figure 3(a) for resistance estimation. The end of the current profile in Figure 1 consists of a pulse current (1A, -1A, 4 pulses, each pulse 20 samples). An enlarged version of the pulse data is shown in Figure 3(b).

- Use this portion of the data shown in Figure 3(b) to estimate the internal resistance R_0 of the battery.



(a) ECM Model-2



(b) Pulse data for resistance estimation (last portion of Figure 1)

Figure 3: Model and data relevant to Question 3

Question 4 (BFG: SOC estimation using Coulomb counting approach)

Use the data provided in TIVdata2.mat (also shown in Figure 2). Assume the initial SOC is $s(1) = 0.8$.

- Compute the SOC using the Coulomb counting approach described in Algorithm 1 for all the $k = 1, 2, 3, 4, \ldots, L$ data points given in the dataset TIVdata2.mat. (here $L = 108,000$).
- Use your BFG to report the SOC at the following points: $t = 1\,\text{hr}$, $t = 2\,\text{hr}$ and $t = 3\,\text{hr}$

Question 5 (BFG: TTS estimation)

Consider the data provided in TIVdata2.mat. Compute the TTS for a given constant current $i_{\text{L}} = 200\,\text{mA}$, not for the current given in the data.

- Compute the time to shut down (TTS), i.e., the time it would take until the terminal voltage reaches OCV_{min} based on the approach described in Algorithm 1 for all the $k = 1, 2, 3, 4, \ldots, 108,000$ data points for an assumed load current of 200 mA.
- Use your BFG to report the TTS at the following points: $t = 1\,\text{hr}$, $2\,\text{hr}$ and $t = 3\,\text{hr}$

What to submit?

- **Report:** Submit a report that clearly details the answers to Questions 1 to 5.
- **Codes:** Submit a Matlab file that outputs the answers to Questions 1 to 5.