Technical University of Denmark

31778 Distributed energy technologies modelling and control

Assignment 1 - Cell modelling and control

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1 Introduction

The correct managing of a rechargeable battery protects it from operating outside of an specified safe operating area, thus maintaining the lifetime and operability of the battery. Based on certain given parameters, the objective of this assignment is to model a Lithium Nickel Manganese Cobalt Oxide (NMC) battery based on the SOC dynamic, 1st order electrical circuit and 1st order thermal dynamic. Several tests are held to observe the behaviour of the battery under certain assumptions and the results are also discussed. Finally, a second model is created under the premise of controlling certain variable with a PI controller, including the tuning of the PI parameters.

2 Mathematical Model

The parameters of the cell were mostly used as given in the assignment. Some minor changes were made:

- The cell capacity (C_{cell}) was converted to [As] instead of [Ah] by multiplying times 3600s.
- Open circuit voltage (V_{oc}) is used in the model as an interpolation through the Lookup Table (see Simulink file and Figure 1).
- Cell mass (m_{cell}) was converted from $[g]$ to $[kg]$.
- Thermal capacitance (C_{th}) was converted from units $[J/kg * K]$ to $[J/K]$ by multiplying with the cell mass (m_{cell}).
- The time step of the simulations were at 1/10 of the smallest system dynamic (the measurement delay of 0.1s), thus the time step is 0.01s.

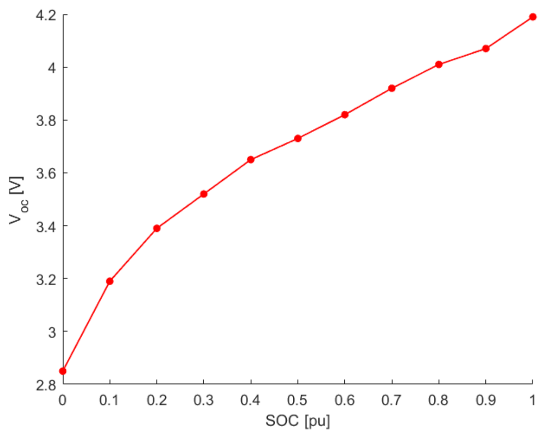


Figure 1: Open circuit voltage as a function of SOC

The SOC Dynamic is modelled exactly as seen in class, where the SOC is both the state variable and output and depends on the following function:

$$SOC = \frac{1}{C_{cell}} \frac{1}{S} I \tag{1}$$

The current I is the input (where negative means charging and positive means discharging) and C_{cell} the battery capacity. The 1st order electricity circuit is also mostly modelled as seen in class with the only change that the V_{oc} is now a function of the SOC. The current I_{cell} is modelled from Ohm's law:

$$I_{cell} = \frac{V_{oc} - V_{cell}}{R_{cell}} \tag{2}$$

Also, V_{cell} is obtained from the derived equation:

$$V_{cell} = \frac{V_{oc}\sqrt{V_{oc}^2 - 4P_{cell}R_{cell}}}{2} \tag{3}$$

The 1st order thermal dynamic represent the change in the battery temperature given its operation and the environment. It is modelled following the function:

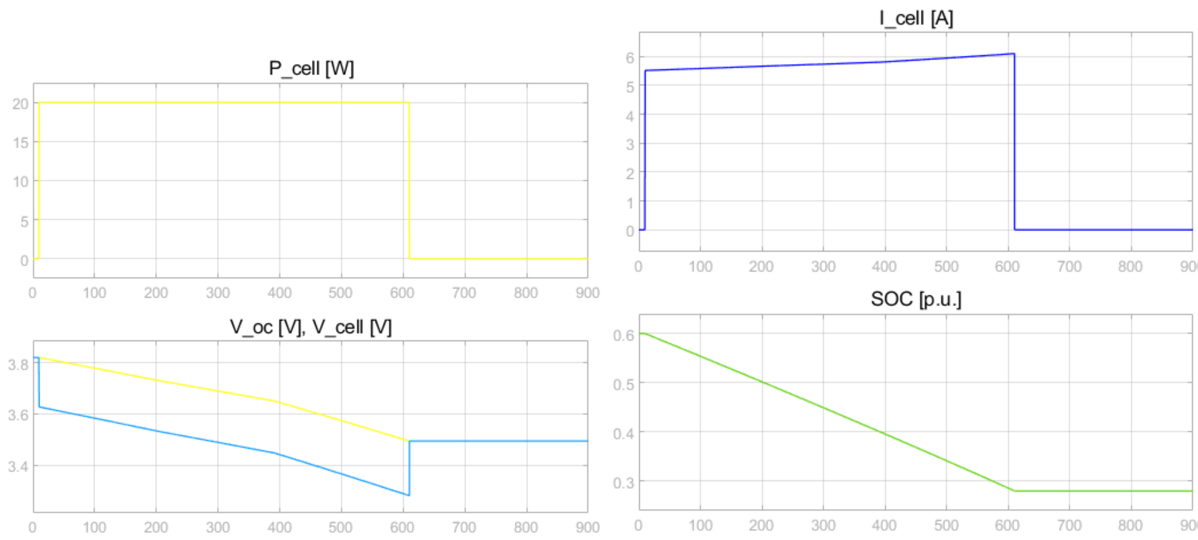
$$T_{cell} = \frac{1}{C_{th}} \frac{1}{S} Q \tag{4}$$

Where Q represents the thermal power balance, given as $P_{loss} - \frac{T_{cell} - T_{env}}{R_{th}}$, where P_{loss} acts as Q_{in} and the power that flows through the internal resistance as Q_{out}.

3 Tests and Results

The first test situation was starting with SOC(0) at 60%, $T_{cell}(0)$ at 20°C (293.15 K) and $T_{out}(0)$ at 20°C. A discharge power of 20W was required from the battery for 10 minutes (600s), with the start of the discharge at t = 10 s. The simulation time is 15 minutes (900s).

As seen from Figure 2, V_{cell} (shown as the blue line) is constant only when there's no power requirement from the cell between 0-10s and 610-900s. Between 10-610s, the cell voltage decreases given equation (3) and following the slope of the V_{oc} given in Figure 1, we can see a more clear change of slope at around second 400, where the SOC changes from 0.4 to 0.3.



(a) Voltages and Power (b) Current and SOC

Figure 2: First test

The Joule losses can be seen in Figure 3, a total amount of 698 W was lost in the process in the internal resistance of the battery.

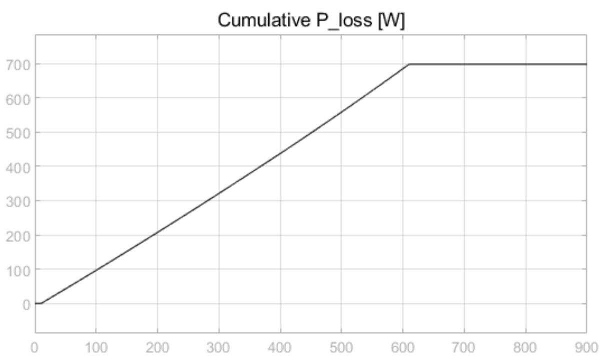


Figure 3: Power loss

This Joule losses can also be seen as Qin in the thermal dynamic, from Figure we can see that the temperature rises during the 10 minutes of power output and then starts to decrease given the constant environment temperature.

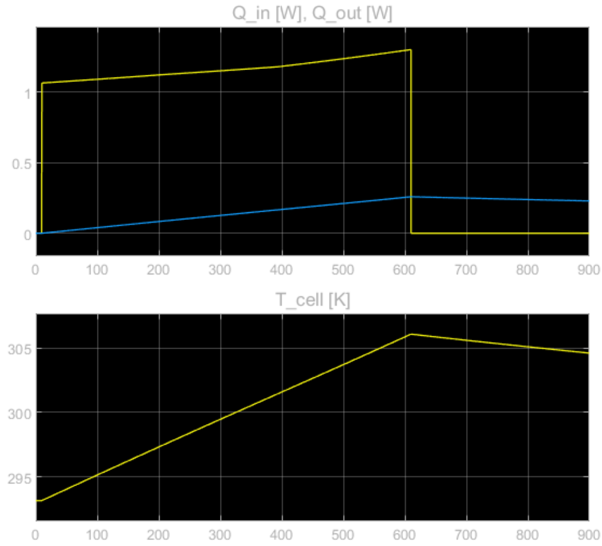


Figure 4: Battery temperature

The time constant is 2400s, given the multiplication of R_{th} and C_{th}. This constant tells us the behaviour of the temperature given an input, so in 5*2400s it should decrease its value to almost its original value.

Finally, the PI parameters of the second model were calculated. First the Ku was found by increasing its value until the state variable oscillates V_{cell}. The Ku was 0.03 for the system, also the period of this oscillatory response was measured at 0.2s. Then The value of Kp was multiplied by 0.45 to obtain the final Kp at 0.0135 and Ki was calculated by multiplying 0.54*Ku/Tu, thus obtaining 0.081 as the parameter.

4 Conclusion

The battery was modelled and tested given certain parameters, then the results were discussed with the simulink file containing the both models. It's important to notice that the time step was necessarily changed to 0.01 given the errors that were found when trying to run it with a variable automatic time step.