Course 46740 – Assignment 1 – Battery modelling and control

- **The assignment is for a 3-person group and shall be completed by Thursday 14/03/2024 at 11:59 AM**
- **TO BE UPLOADED**: one Simulink file and a short narrative document (6 pages). Kindly rename the uploaded files as follows: A1_s123456_Surname_s123456_Surname.filetype (slx/pdf). It is required to upload just Simulink files (no .m files) so that the file can be executed independently on your workspace.
- **Starting conditions**: Simulink file including the NMC battery model similar to the one built in Lecture 04-05 and one .mat file including a power profile (in Watt) as a function of time (in seconds), a speed profile (in rpm) as a function of time (in seconds), and an external air temperature (in Celsius) as a function of time (in seconds). The .mat file also includes two matrices that are used to describe the Voc-SOC and R-SOC as per table below.

OBJECTIVES:

1) Starting from the NMC battery model provided (10.8 kWh), find the battery cells configuration (series and parallel number of cells) so that:

Nominal Cell Voltage	3.65 V
Nominal Cell Capacity	58.8 Ah
Nominal Battery Capacity	61.8 kWh
Nominal Battery Voltage	350.4 V

Modify the provided Simulink model in such a way:

Min.-Max. Cell Voltage	2.9-4.2 V
Min.-Max. SOC	5-95%
Nominal Cell Current (Crate=1)	58.8 A
Battery Mass	309 kg
Specific Heat Capacity (cp)	1030 J/(kg*K)
Thermal Resistance (Rth)	0.185 K/W

Adjust the open circuit voltage and resistance as shown in the table below (interpolate linearly between values), assuming no temperature dependency for the resistance.

SOC [%]	Voc (V)	R (mΩ)		SOC [%]	Voc (V)	R (mΩ)
3.0%	3.20	4.14		53.0%	3.68	4.72
5.0%	3.35	4.14		57.5%	3.70	3.84
6.7%	3.41	4.14		61.7%	3.74	3.59
11.7%	3.45	4.28		66.1%	3.79	3.71
16.5%	3.48	3.84		70.5%	3.84	3.99
21.0%	3.51	3.72		74.9%	3.88	4.33
25.6%	3.56	3.71		79.1%	3.93	4.66
30.3%	3.60	3.82		83.3%	3.98	4.97

35.0%	3.62	4.05		87.3%	4.02	5.32
39.7%	3.63	4.43		91.4%	4.07	5.32
44.4%	3.64	4.83		94.5%	4.13	5.32
48.6%	3.66	4.78		97.0%	4.18	5.32

2) Start with SOC(0) = 95%, $T_{batt}(0)$ = 10 °C and $T_{out}(0)$ = 10 °C. Assume the outside temperature constant. Set a discharge at 20 kW (DC side), for 180 minutes (start the discharge at t = 60 s and make it last until t = 10860 s) followed by a charge at 62 kW (DC side) for 60 minutes (start the charge at t = 11000 s and make it last until t = 14600 s). Run the simulation for 17500 s.
   a) Discuss in the narrative document the dynamic behavior of the model. Is it able to follow the desired charge/discharge setpoint? What is the minimum/maximum SOC reached throughout the simulation?
   b) Calculate how many losses are generated in the process (consider the thermal losses to the outside air as well). Can you explain why the temperature keeps rising? Assess the Ah throughput of the battery and equivalent full cycles.
   c) What is the maximum temperature reached? Which range does the internal resistance in per unit span?

3) Duplicate the model from question 1)-2) (keep it in the same Simulink file) and, in the "Thermal dynamics block", add a constant 4 kW cooling source that activates when the internal temperature of the battery reaches 35 °C, and deactivates when the temperature is less than 25°C (Tip: use the "relay" block to perform this task and consider a measurement delay of 0.1 s). Do not account for the cooling power in the DC battery power reference. Run the simulation for 17500 s.
   a) Comment on the dynamic behavior of the temperature.
   b) Do Joule and Inverter losses change significantly? How much heat is dissipated by the cooling unit? How much energy is lost to the outside air? Why is this last value different from the previous case?
   c) Now change the outside temperature to 25 °C and comment on the dynamic behavior of the temperature. Do you see any difference in the previous values? How much electric energy is consumed by the cooling unit? Consider a Coefficient of Performance (COP) of 5.
   d) Considering that the cooling unit is powered by the battery, how much does the instantaneous power absorbed by the battery increase during the discharging phase? Is this value affected by the COP value?

4) Duplicate the model from point 1)-2), without the cooling unit, keep it in the same Simulink file, and perform a simulation lasting 96 h. Set the initial battery temperature at 40 °C but keep the ambient temperature to 10 °C (constant). Keep SOC(0) = 95%. Do not provide any power profile to the model.
   a) Assess if part of the model can be removed for this investigation to speed up the simulation without losing information. Comment in the narrative document any interesting finding generated by this simulation.

5) Duplicate the model from point 3), including the cooling system, and, by using the .mat file present in the assignment import the "power_hist", "Tout", and "rpm_hist" profiles. Tip: use a "from workspace" Simulink block. The profiles represent timeseries with the power flow in W at the battery terminals, the revolutions per minute and the external

air temperature in Celsius degrees for a 499.5 km trip including three fast charging sessions that Mattia took on the way from Denmark to Italy a few years back. Test the model in Simulink, do not account for the cooling consumption in the DC battery power setpoint. Start with SOC(0) = 95%. Set the initial battery temperature to the initial value of Tout. The requested power represents the inflow/outflow at the battery terminals either for driving or fast charging. Perform a simulation for the duration of the profiles.

a) Discuss in the narrative document the behavior of the model and the reasoning behind the answers to the following questions. Is the battery able to follow the desired charge/discharge setpoint? What is the minimum/maximum SOC reached throughout the simulation? How much is the Ah throughput of the battery and the equivalent number of full cycles? What is the maximum battery temperature reached? How much energy has been consumed while driving and how much has been charged?
b) What is the average driving consumption in Wh/km (including regenerative charging)?
c) Finally, create a scatter plot (just in Matlab, no need for the Simulink model) of (positive) power vs (positive) rpm. Tip: in the scatter() function, set the ‘MarkerFaceAlpha’ parameter to a value lower than 1 to highlight the parts with the highest density, and use the ‘filled’ option. Considering that the vehicle motor has peak power of 160 kW, comment on the content of the plot.

Notes for the Simulink file and the narrative document:

- Clearly identify the four models generated in the Simulink file (suggestion: comment out the model that is not needed for the specific investigation).
- Figures in the narrative document should be clear and readable.
- Keep the narrative discussion short and to the point.
- Clearly list in the narrative document all changes made to the models.