Course 31778 – Assignment 2 (NON-graded) – Hybrid power plant

- **Starting conditions**: mat files including a daily pattern for a 10 kW (on the AC side) PV plant production in May (86400 second-values); air temperature and power reference for the hybrid plant (25 hourly-values, from midnight to midnight). Simulink file including the NMC battery model built in Lecture 04-05. Note, interpolate in Simulink the PV power profile and air temperature. Do not interpolate the power reference instead (otherwise you will lose the step characteristic).

OBJECTIVES:

1) Starting from the NMC battery model provided (10.8 kWh), scale the model to have the following characteristics: 16.2 kWh and nominal DC voltage 540 V. Scale with reasonable factors also the thermal parameters. Calculate, discuss and report in the narrative document the calculations that determine the numbers of cells in series and parallel and the thermal properties.

*The individual cells have a nominal voltage of 3.6 V so to get a nominal pack voltage of 540 V, we need 540/3.6=150 cells. Each cell has a Wh-capacity of 3 Ah*3.6 V=10.8 Wh, so to get a capacity of 16.2 kWh we need 16200 Wh/10.8 Wh = 1500 cells. Since we already have put 150 cells in series, we need 1500 cells/150 cells = 10 cells in parallel.*

*The number of cells increased with 50% so the thermal capacitance also has increased with 50%, 72000 J/K*1.5=108000 J/K. It is unknown how the new cells are located relative to the old so the thermal resistance is kept the same.*

2) Design (and tune) in Simulink a controller necessary to smoothen the power output of the combined system (PV+storage). Ensure a constant power output equal to 6.5 kW for 10 hours at the PCC (point of common coupling), between 7 AM (=25200 s) and 5 PM (=61200 s), as per power reference given (see block diagram in the lecture slides).

The Point of Common Coupling (PCC) is measured with 0.5 s delay and then subtracted from the reference of 6.5 kW. The reference is 0 before 7 AM and after 5 PM. The power reference is sent to the battery. It is necessary to make a PI controller to adjust the output of the battery to avoid a steady state error. The power reference is limited to +/- the nominal power with a saturation block, but it can be seen that it is not necessary in this case as the controller signals never reach that level. Its role is critical especially to enable the operation of the anti wind-up of the integrator.

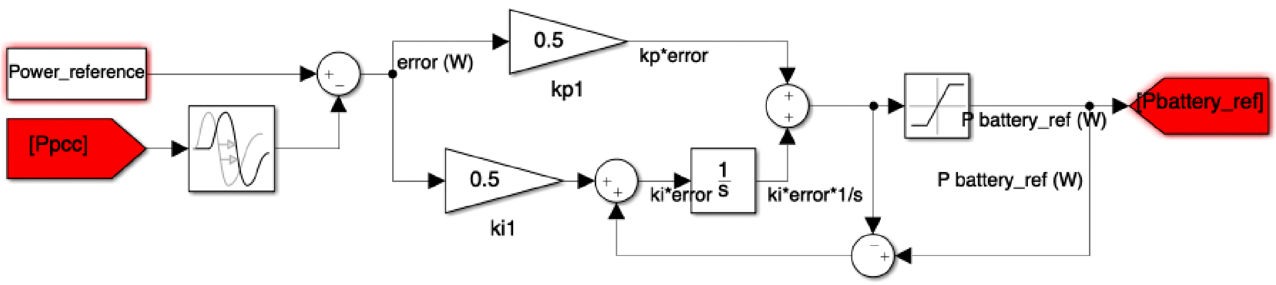


Figure 1 PI Controller, with equal proportional and integral gain of 0.5

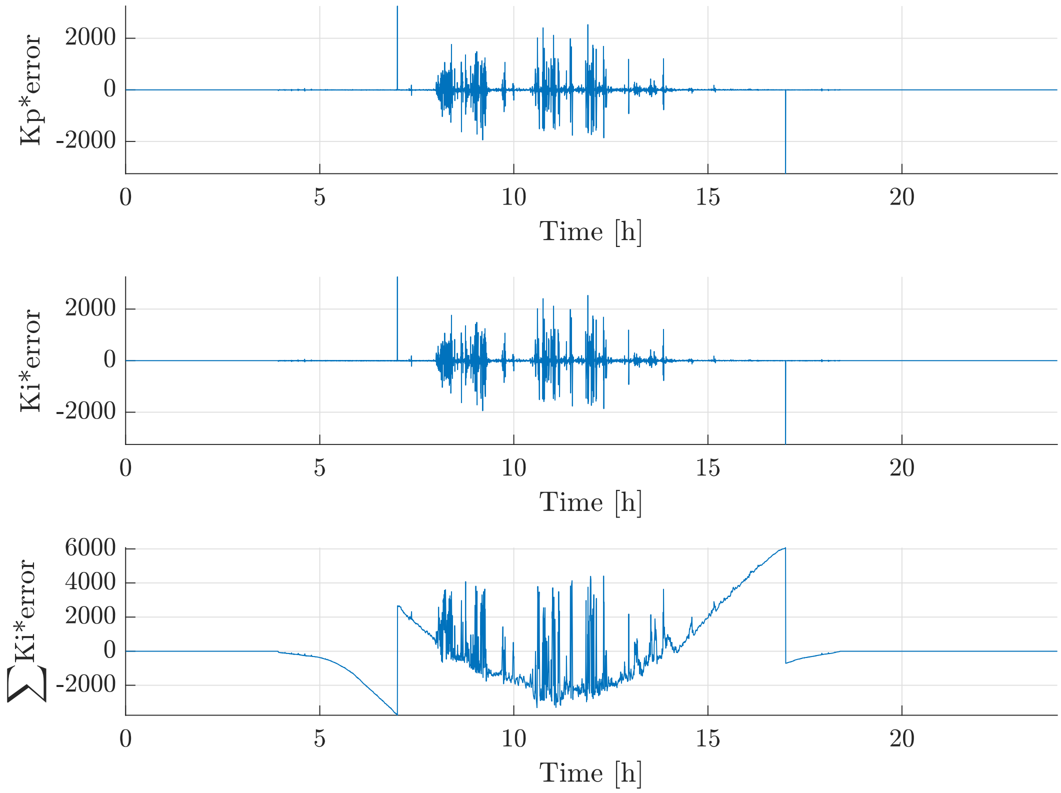


Figure 2 Error signals for proportional, integral before integrator and integrated gain.

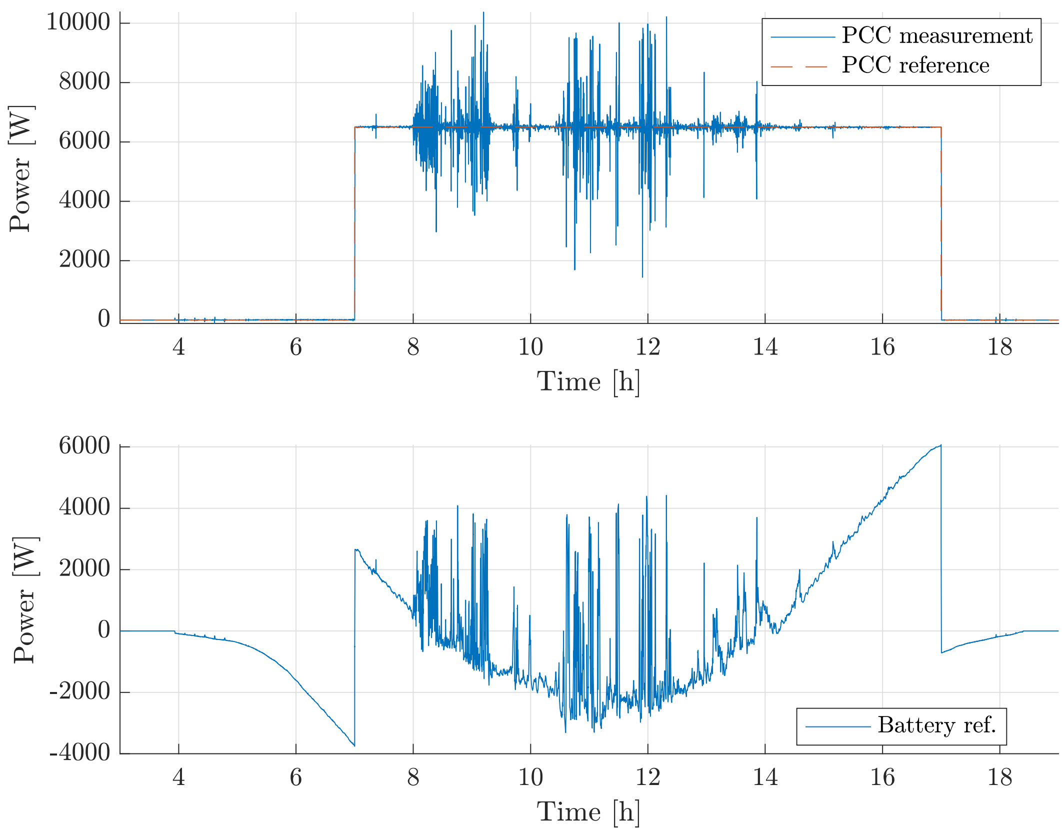


Figure 3 Top Fig.: Given Power reference at PCC and measured power at PCC. Bottom Fig.: Battery Power reference sent from controller to the battery. (Zoom in on time 03:00 to 19:00 where there is activity)

3) Assume 0.5 seconds as measurement&communication delay on the power output of the hybrid plant (remember the inverter has a 0.1 s latency). What is a feasible initial SOC for the storage in order to ensure proper operation throughout the day? Is the power/energy size sufficient? Is it fast enough (you could try to see how small the latencies need to be to reach a “reasonably” smooth power profile)?

The initial SOC is set to 40% because it first needs to discharge in the morning when the production is too high and then charge in the middle of the day. That is found to be a fine choice, as the SOC moves between 30 and 90%. The size of the battery is found to be sufficient. It is impossible to avoid fluctuations in the output when the PV production fluctuates very fast and there is such measurement delay. For grid connected hybrid plants, the spikes at the PCC would be acceptable as the equipment would not take any harm nor the grid would be unstable. Those spikes instead could be challenging in an isolated system.

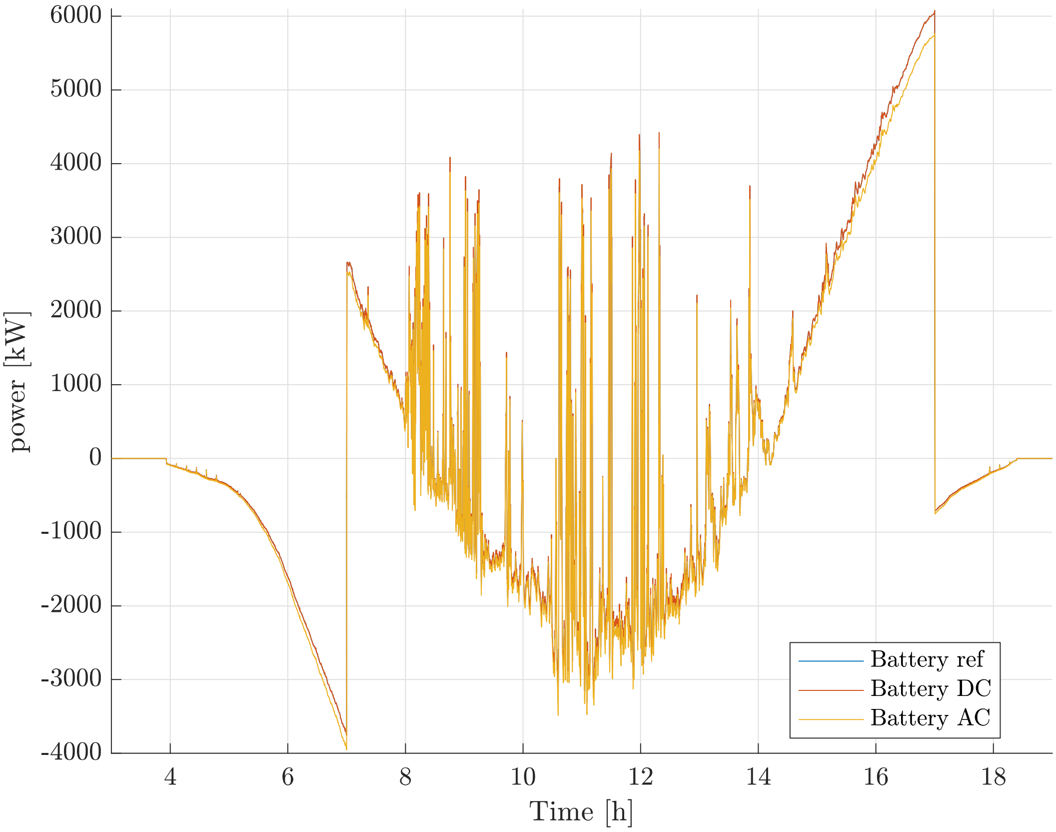


Figure 4 Power request sent to the battery, DC power delivered and AC power delivered.

There is no visible difference between requested power and DC power. The AC power is (slightly) larger while charging (to account for the inverter losses) and smaller while charging (positive power) to account for the losses.

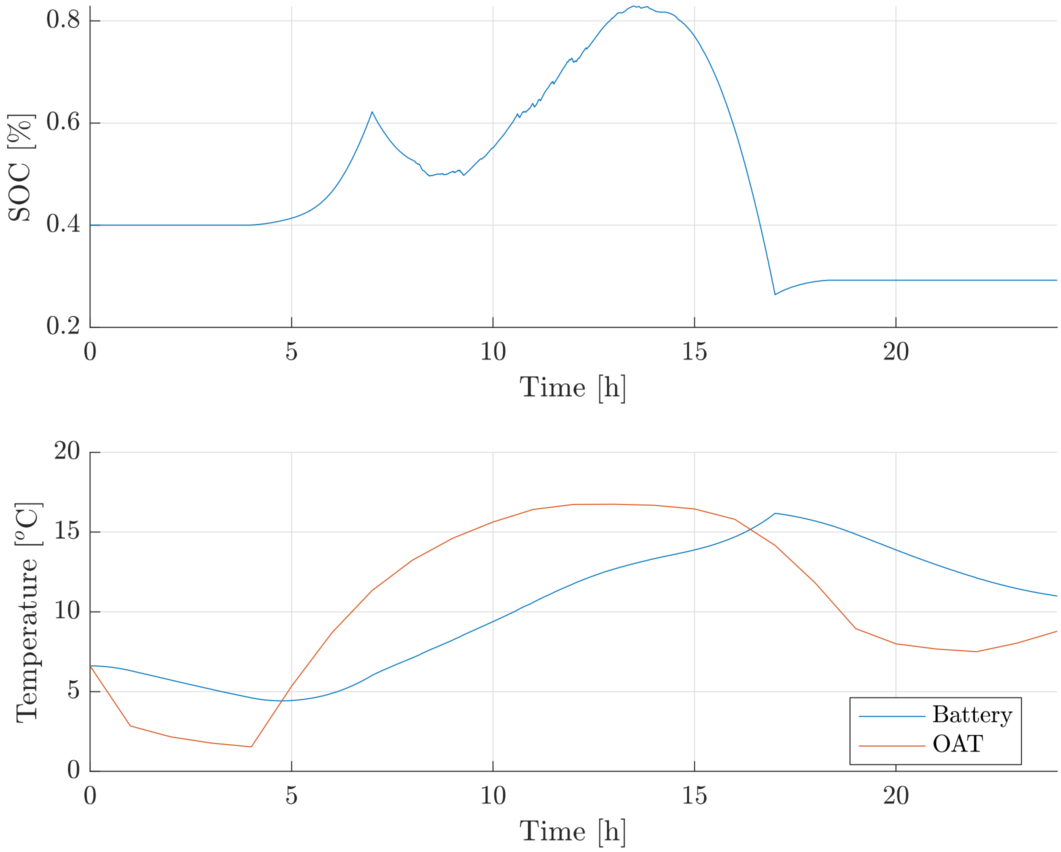
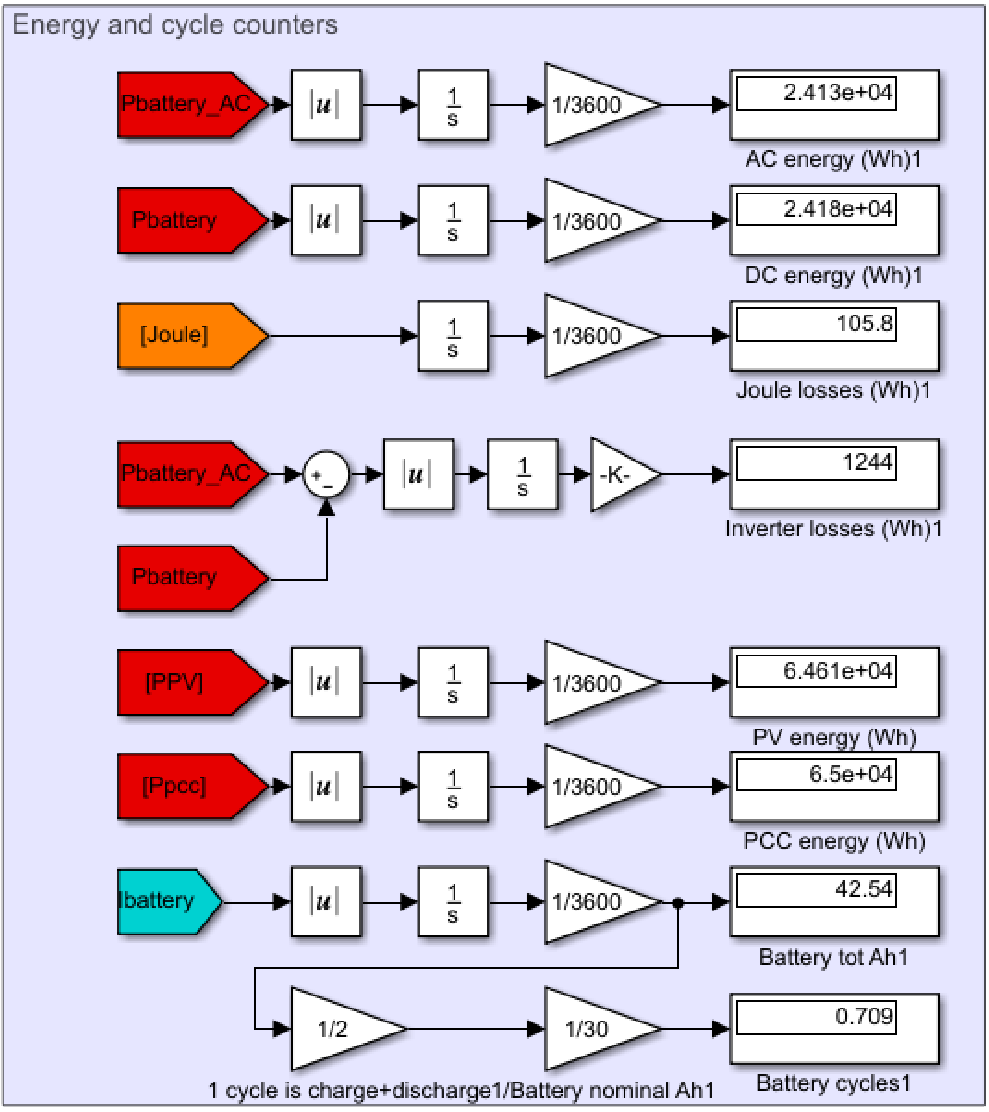


Figure 5 Top Fig.: SOC of the battery. Bottom Fig.: Internal battery temperature and Outside Air Temperature (OAT).

4) Assess the energy lost throughout the day, the Ah throughput of the battery and equivalent cycles. Compare and report in the narrative document the numbers with the produced PV production and overall energy flow towards the grid.

To be able to compute the losses, it is necessary to input the outdoor air temperature (OAT) in the model, because it affects the internal resistance. The initial battery temperature is in the model set equal to the OAT. It can be seen that the battery temperature decreases when it is warmer than the OAT and wise versa, but it increases steadily when there is a power flow and large changes in the SOC.

The inverter losses are 1244 Wh and the joule losses are 106 Wh, giving a total loss of 1.35 kWh, which is only 5.5% of the 24.14 kWh AC throughput (mostly due to the 95% efficiency in the inverter). The battery experiences a current throughput of 42.5 Ah, but the for a 30 Ah battery it only corresponds to 0.71 cycles.



The PV plant is producing 64.6 kWh and almost the same, 65 kWh are sent to the grid. The export is a bit more than the production because of the reduced SOC (initial 0.4 vs final 0.292), which implies a 1.75 kWh being released by the battery. This difference accounts for the difference between 64.6 kWh and 65.0 kWh and the losses (1.35 kWh).