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# Background

Use Matlab and Simulink to solve tasks below.

Use the example scripts in “Assign4.zip” uploaded at Canvas. Use the latest version published version published. The main Simulink model is “EDR100\_Model4.slx”.

When asked for numerical answers, use max four significant digits and include physical quantities as a part of the answer whenever possible or relevant.

If nothing else is stated, use the default vehicle parameters defined in Lecture 1.

Good practice for plots:

* Give the plot a descriptive title, e.g. to know what the data source is.
* Always label all axes with physical quantity and the relevant unit.
* Try to scale the data with prefixes (milli, kilo…) so that the data labels on the axes are as short as possible, and hence easy to read.
* Simulink plots will include labels if you manually label the signals going into the scope, and enable “lagend” in the scope options.

MathWorks offer excellent help sections for Matlab and Simulink. Try typing “doc plot” in the command window to open the help section for plotting. There are also vast archives of Q&A available online through MathWorks forums, StackExchange and many more.

Example on a great plot:

Chart, surface chart

Description automatically generated

# Tasks

1. **ESS design**Design you own battery, using the parameters for the cylindrical cells presented at lecture 4. Some cell parameters are already filled in in the new init-file, you have to fill in the rest as a part of this assignment. You need to figure out series and parallel connection to get the right voltage and energy capacity.  
   The target maximum pack voltage should be close to 400 V (**not larger than 400V**) at 100 % SOC. A typical entry-level EV has a battery pack of 60 kWh (**not less than 60 kWh**) nominal capacity. You can calculate this task by hand or any method you prefer.

**Battery cell data: 5Ah, 4.15V (100% soc), 3.65V (nominal, 50% soc), 0.07kg**

* 1. How many cells in series are needed to reach the voltage level of 400 V? (1)  
      **Answer: 96 cells (398.4V)**
  2. How many cells in parallel are needed to reach the energy capacity of 60 kWh? (1)

**Answer: 35 modules á 96 cells in series (61.13kWh)**

* 1. What’s the total weight of all cells in the configuration you selected? (1)  
      **(just cells)**

**(Whole Pack)**

* 1. Fill in these ESS parameters in your init-file and paste your result here (1):  
     ESS\_cell\_Qmax = *5*; Ah  
     ESS\_cells\_series = *96*;   
     ESS\_cells\_parallel = *35*;

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Automatiskt genererad beskrivning

1. **ESS simulations**  
   Insert/change the relevant battery parameters from task 1 into the init-file and open Simulink to simulate the vehicle behavior. Start at 90% SOC. Run a simulation with standard vehicle parameters, and using the WLTC.
   1. Plot the signals “Drive cycle speed”, “SOC”, “Voltage” and “Current” for the total ESS (pack level) in separate figures and insert the figures here. (4)  
      *En bild som visar text, linje, handskrift, Teckensnitt

      Automatiskt genererad beskrivning*
   2. You can probably see the general trend of the SOC being a negative slope. Sometimes, though, the SOC slope is positive, what happens in the powertrain in the simulation during positive SOC slopes? (1)  
      **Retardation of vehicle and “regen” kicks in. EM becomes generator and the inverter becomes a rectifier. Power direction flips.**
   3. Plot loss power (Watts) from ESS, PEC, EM, Gearbox in the same figure (four lines in one window, sharing the same x-, y-axle) and include a screenshot here. How big are the ESS losses in peak? What happens in the drive cycle during the same time instance as the ESS peak power? (4)

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Automatiskt genererad beskrivning

**ESS losses peak: 902.2094 watt at 1567 seconds  
The ESS peak occurs when all the other losses add together and in turn has the highest peaks. This when the greatest acceleration phase occurs in WLTC drive cycle (0 to 34 m/s).**



* 1. Use the results and the plot from c), but answer how big are the PEC losses in peak. What happens in the drive cycle during the same time instance as the PEC peak power? (2)  
     **

**PEC losses peak: 588.6323 watt at 1031seconds**

**Greatest loss in PEC occurs when vehicle accelerates the hardest and there for has the highest current peak.**

* 1. Plot loss energy (Joules) from ESS, PEC, EM, Gearbox in the same figure and include a screenshot here. Which component has accumulated the most loss energy at the end of the drive cycle, and how much is it? Don’t just point at the peak point in the figure, give some words and the exact value. (4)  
     En bild som visar text, linje, diagram, Graf

     Automatiskt genererad beskrivning

**We can see that the EM accumulate the most losses, then TM, PEC and lest accumulated losses have the battery pack.**

**Total accumulated losses of EM: 684.7143 kJ**

**Total accumulated losses TM: 318.8321 kJ**

**Total accumulated losses PEC: 212.5513 kJ**

**Total accumulated losses ESS: 125.6192 kJ**

1. **ESS parameter sensitivity**  
   Make a parameter sensitivity analysis on the battery cell internal resistance by changing the scaling factor ESS\_cell\_R\_scaling:
   1. Nominal value, i.e. scaling to 1. Run the model and analyze the total energy losses (Joules) in the ESS. Write out the end value of the losses with a screenshot. (2)  
      

**Total accumulated losses ESS: 125.6192 kJ**

* 1. Scale the cell resistance to 0.5. Run the model and analyze the total energy losses (Joules) in the ESS. Write out the end value of the losses with a screenshot. (2)  
     **

**Total accumulated losses ESS: 62.3129 kJ**

* 1. Scale the cell resistance to 2. Run the model and analyze the total energy losses (Joules) in the ESS. Write out the end value of the losses with a screenshot. (2)  
     **

**Total accumulated losses ESS: 255.4484 kJ**

* 1. Scale the cell resistance to 3. Run the model and analyze what happens. Insert relevant plots and printouts and write your comment of what happened in the model. (2)  
     **

**Total accumulated losses ESS: 56.8824 kJ**

**Simulation stops at 796 seconds due to “ESS cell over-voltage error!**

**stop =**

**1”**

****

**We can se that in the drive cycle we are slowing down and there for regenerating. But now the resistance in the battery cell is high the battery can’t accept as big a current so the voltages starting to rise. And finally, it reaches the set maximum value. ESS\_cell\_Vmax = 4.15 V.**

**Internal resistance of a battery is the main limiting factor on how high current it can deliver/receive.**

* 1. Compare the loss numbers from task a) through c) above. What is the correlation with the scaling factor? (1)  
     ***It is almost directly proportional with total accumulated power loss. The main loss in an ESS is thermal losses in battery cells and that intern depends on how high the internal battery resistance is.***

1. **PEC and EM scaling 1 - car**The Simulink model features scaling factors for EM and PEC, found as EM\_scaling and PEC\_scaling. The default values are 1.0, which means the Simulink model use an unscaled value of the original input parameters (i.e. Nissan Leaf EM look-up-tables from MotorCAD and Infineon FS820 datasheet transistor and diode loss data). If you would like to build a vehicle with less, or more, motor power, the performance can be scaled in a linear way with the parameters above.
   1. Reference case. Run default vehicle with both scaling factors set to 1. Extract the total energy losses (Joules) for EM and PEC and write here: (2)  
      **Combined accumulated losses of EM and PEC: 897.2655 kJ.**
   2. Scale 0.5 on both EM and PEC. Run the model. Extract the total energy losses (Joules) again, and compare with the values in a). Is it bigger or smaller, and why do you think if that is the case? (3)  
      **Combined accumulated losses of EM and PEC: 1365.0 kJ.**

**Here we have scaled down the torque capability of the EM and power capability of the PEC. This means that the system needs to work much harder to follow the WLTC and a direct consequence is that the losses also rise.**

* 1. Scale 2.0 on both EM and PEC. Run the model. Extract the total energy losses (Joules) again, and compare with the values in a). Is it bigger or smaller, and why do you think if that is the case? (3)  
     **Combined accumulated losses of EM and PEC: 791.8738 kJ.**

**Here we have doubled the torque capability of EM and PEC. This means that the system has a better headroom and there for an easier time to follow the drive cycle. There for we have lower losses.**

1. **PEC and EM scaling 2 – truck**In order to increase the power consumption in our simulation, we need to change the vehicle parameters. Let’s pretend we drive a medium truck, with total mass of 6 000 kg and aerodynamics of Cd = 0.6 and A = 5 m2. Other parameters unchanged. Use WLTC.
   1. Run with both scaling factors set to 1. What happens in the simulation? Plot motor torque (Nm) and use it to explain. Notice: error message is shown in the Diagnostic Viewer at the bottom of the Simulink window. (2)  
      **we hit torque limit of the EM after just 15 seconds. This due to that we are trying to run a truck of 6 tons with a Nissan leaf motor.**



**Max torque : 332.5461 Nm**

**“ans =**

**1**

**EM over-torque error!”**

* 1. Experiment with EM and PEC scaling factors until you get satisfactory results. You might need to trim the ESS parameters also. Show plots/graphs of a successful simulation, total energy losses for EM and PEC and comment on what parameters you changed (and values), and how you reasoned to get there. (4)  
     *I reasoned that a truck of 6 tons is ruffly 3 times of a Nissan leaf (Nissan leaf 2022 is 2 tons) so I started by scaling up EM and PEC by 3. I noticed then that I had problem with over discharge of battery cell. So, I tried tweaking battery values. I found that simply scaling the internal resistance didn’t help. So, I thought a truck battery is larger so first I tried only to change number of parallel modules in battery pack. But didn’t help. Then I read through the code and comments and found that the discharge of cells was determined by cells Qmax (Ah per cell) and its c value. I reasoned that it probably has a bigger battery cell as well. So, I changed Qmax to 6 Ah.*

**I want to point out that keeping the same gear ratio is highly unlikely. But outside this questions scope. Otherwise, I’d change the gear ratio as well. Used the calculation in assignment 3 to see what GR I needed for a top speed of around 130 km/h. Then I might not have to scale up as much.**

|  |  |  |
| --- | --- | --- |
| parameters | default | New value |
| ESS\_cell\_Qmax | 5 | 6 |
| ESS\_cells\_parallel | 35 | 50 |
| PEC\_scaling | 1 | 3 |
| EM\_scaling | 1 | 3 |

**Total accumulated losses EM: 763.9403 kJ**

**Total accumulated losses PEC: 1078.1kJ**

1. **Energy efficiency**  
   It can be tricky to calculate, or even define, the energy efficiency for traction components for every time instance, since the operation often shifts from motor mode to generator mode. However, since our model is designed to operate a full drive cycle, we can look at the total energy losses at the end of the cycle and compare the loss energy at the end of the cycle. The ESS has an output ESS E\_tot (J) that outputs the total used energy in the battery including all losses. For the same vehicle and battery setup you used in task 2, calculate all component efficiencies ( using this general definition: 
   1. ESS efficiency = 0.9874 (98.74%) (1)
   2. PEC efficiency = 0.9787 (97.87%) (1)
   3. EM efficiency = .0.9315 (93.15%) (1)
   4. GB efficiency = 0.9681 (96.81%) (1)
   5. System overall efficiency = 0.8658 (86.58%) (1)
   6. Where does the rest of the energy go, and how? Explain for each component (ESS, PEC, EM, and GB) in text. (4)  
      *ESS losses are mainly heat buildup in battery cells due to internal resistance.*

PEC losses are switching losses in form of IGBT forward channel voltage drop, forward resistance drop, reverse diode conduction, Diode reverse recovery.

EM losses heat buildup in coils and rotor plus friction.

GB thermal losses due to friction.