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# Background

Use Matlab and Simulink to solve tasks below.

Use the example scripts in “Assign4.zip” uploaded at Canvas, i.e. same model as in Assignment 4. No new modules or features are added or needed for this Assignment since last lecture module 4. Use the latest version published. The main Simulink model is “EDR100\_Model4.slx” with the corresponding init-file.

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

Unless otherwise explicitly instructed, use these default parameters:

* Default vehicle parameters for “car” defined in Lecture 1
* Slope=0 for the drive cycle
* Start the simulation from 90% SOC
* Use the WLTC drive cycle provided in the zip-file together with the Simulink model

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 in to 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’s 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. **Range estimation**

Use the reference car parameters.

Use the battery designed in Assignment 4, task 1. One solution is:

96 cells in series, 35 cells in parallel, 5 Ah per cell.

Run three different drive cycles, where one is WLTC. You pick two other relevant cycle on your own. Paste the speed-time profile of the drive cycle below.

Write down the energy efficiency at the end of the simulation for each drive cycle.

Calculate the maximum available electrical energy in the battery at 0-100 % SOC and assume all of it can be utilized in this case. The target capacity was 60 kWh, but the actual implemented is probably slightly different.

Estimate the total range by using maximum battery energy available and divide by energy efficiency in one cycle. Find the maximum mechanical power used in the drive cycle.

Fill in the field in this table. (12 points)

|  |  |  |  |
| --- | --- | --- | --- |
|  | WLTC | UDDS | NYCC |
| Energy consumption in one drive cycle (Wh/km) | 113.7 Wh/km | 82.27 Wh/km | 80.58 Wh/km |
| Battery capacity (kWh) | 61,32kWh (35 parallel 96 serial ) | | |
| Estimated range with 0-100% SOC battery (km) | 539.3140 km | 745.0790 km | 760.7940 km |
| Maximum power consumption at the wheel axle (kW) *(wheel\_torque(Nm) \* wheel\_speed(ω))* | 43.4705 kW | 35.9165 kW | 31.4528 kW |
| Average speed in drive cycle (km/h) | 46.5067 km/h | 31.5072 km/h | 11.4097 km/h |

Include your drive cycle profiles here (3 points)

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Why do you see a difference in estimated range in the different drive cycles? Hint, look at max speed, average speed, max acceleration in the drive cycles, is there any connection to consumption? Explain with less than 150 words (2 points)

*The main reason for the difference is the top speed, average speed and acceleration. Sence the consumption is “normalized” to Wh/km it doesn’t matter how long the cycle is (but more accurate the longer the cycle is). We can see in the graphs that the top speed differs, and there for also the acceleration to that top speed. We can also see that there is more stop and goes in the UDDS and NYCC cycles. That will affect the range negatively, but it also gives some of that energy spent, back in the retardation (regen). In case of NYCC we have relatively long times where we stand still and there for no power consumption (because in model the power used for car aux. systems aren’t included), that will increase range. In the case of UDDS and WLTC they are quite similar in profile. The main difference is top speed / average speed and acceleration. And we know that most power is needed when accelerating hard and for a long time. There for the WLTC range is shorter.*

1. **Large ESS and secondary effects**

Let’s investigate what happens if we want to use a much larger battery system in the car, to get more range or to get more performance in the traction system.

Use the reference car parameters.

ESS 1: 60 kWh (96 cells in series, 35 cells in parallel, 5 Ah per cell).

ESS 2: 120 kWh (96 cells in series). Calculate any combination of cell size and parallel connection that fulfills the requirements. Fill in the table below.

The ESS 2 design is supposed to offer twice as much energy, and nominally twice the range. But now, the secondary effects will play in. Batteries have a significant mass.

Calculate the weight of the cells and the total ESS. There’s a rule of thumb in lecture 4 about cell-to-pack weight ratio. Fill in the table below.

Run two simulations, one for each ESS. Use WLTC drive cycle.

Assume the mass of ESS 1 is included in the total mass of the vehicle (1700 kg).

Modify the m\_v for the case where ESS 2 is used, so that the added battery mass is represented in the vehicle losses. Assume the car has enough space and volume to fit the larger ESS, i.e. Cd or A does not need to change.

Estimate the range in the same manner as task 1.

Fill in the field in this table. (12 points)

|  |  |  |
| --- | --- | --- |
|  | ESS 1 | ESS 2 |
| ESS\_cell\_Qmax | 5 | 5 |
| ESS\_cells\_series | 96 | 96 |
| ESS\_cells\_parallel | 35 | 69 |
| Cells only mass (kg) | 235.2 | 463.68 |
| Rest of ESS mass (kg) | 121.1636 | 238.8655 |
| Total ESS mass (kg) | 356.3636 | 702.5455 |
| Energy consumption in one drive cycle (Wh/km) | 113.7 Wh/km | 124.4 Wh/km |
| Estimated range with 0-100% SOC battery (km) | 539.3140 km | 964.6302 km |

What is your finding/conclusion? Did the range double with twice as large ESS capacity? If not, what is the absolute and relative (e.g. %) range increase? (2 points)

No, it does not give double the range.

*Range increase is 425.3162 km. That is a 78.86% increase in range.*

What are the total losses in the ESS for your two simulation cases, respectively? Which of the two batteries offer the higher energy efficiency? (2 points)

*ESS losses 60 kWh: 36.92 Wh*

*ESS losses 120 kWh: 49.01 Wh*

*The smaller ESS is more efficient. (less batteries to cool)*

What is the reason that double range is not achieved with ESS 2? Where does the energy go? What are the drawbacks and potential benefits in losses/energy efficiency of a larger battery, apart from increased energy storage? Explain with less than 150 words. Include graphs or plots to explain if necessary. (2 points)

Main reason that double range is not achieved is mass/weight. The vehicle gets heavier hand there for harder to change its speed, higher inertia. More energy is needed to accelerate the vehicle. So, if we could get double the capacity with no weight gain and same efficiency, we will get double the range.

1. **Acceleration test**

Design a traction system (all parameters) for the reference car, a 100 kWh battery at 400 V max, to perform well at a 0-100 km/h acceleration test. Include the added weight of a bigger battery compared to the reference car having a 60 kWh battery.

The same car design should also be able to run up to 200 km/h without over-speeding the EM. Design the gear ratio to support this speed.

Decide your acceleration target yourself, i.e. the time it takes to reach 100 km/h from standstill. Suitable acceleration rates are 1.4-11 m/s².

Feel free to iterate your parameters and run the model until it works ok, e.g. “trial and error”. When you are content with the simulation results, fill in the parameters below.

|  |  |
| --- | --- |
| **Parameters** (6 points) | **Value** |
| Max speed | 200 km/h |
| Target acceleration time | ?? s |
| Resulting average acceleration | ?? m/s² |
| ESS\_cell\_Qmax | Your answer here |
| ESS\_cells\_series | Your answer here |
| ESS\_cells\_parallel | Your answer here |
| ESS\_cell\_Cvalue | Your answer here |
| ESS\_cell\_R\_scaling | Your answer here |
| m\_v | Your answer here |
| GB\_ratio | Your answer here |
| EM\_scaling | Your answer here |
| PEC\_scaling | Your answer here |

Explain your biggest challenges and findings while tuning your parameters and solving this task. What did you learn, how do the different components (EM, PEC, ESS, GB) affect the acceleration? Explain with less than 150 words (2 points)

*your answer here*

1. **Car parameter sensitivity analysis**

What happens if we are allowed to slightly trim the parameters of the car? I.e. better tires, different C\_d \* A\_f, other mass? And how does it compare with having better/bigger/more efficient traction components? Vary the vehicle parameters listed in the table below with nominally ±25%, fill in the parameter value you used, run one simulation for each case, and fill in peak wheel power and energy consumption for the WLTC (Wh/km) for every simulation.

Use the reference car parameters with ESS 1 from task 2:

60 kWh (96 cells in series, 35 cells in parallel, 5 Ah per cell).

Secondary effects need not to be considered in this task.

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameters** (30 points) | **-25%** | **Ref value** | **+25%** |
| c\_d \* A\_f | Your answer here | 0.644 | Your answer here |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| c\_r | Your answer here | 9/1000 | Your answer here |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| m\_v | Your answer here | 1600 kg | Your answer here |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| d\_wheel | Your answer here | 0.6487 m | Your answer here |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| EM\_scaling | Your answer here | 1.0 | Your answer here |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| PEC\_scaling | Your answer here | 1.0 | Your answer here |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| R\_int\_scaling | Your answer here | 1.0 | Your answer here |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| PEC\_P\_aux | N/A | 0 W | 1000 W |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |
| eta\_gear | 0.97 | 0.98 | 0.99 |
| Peak wheel power | Your answer here | Your answer here | Your answer here |
| Energy consumption | Your answer here | Your answer here | Your answer here |

With your findings in running the simulations and filling in table above, what is your opinion on how to best minimize energy consumption of the car in the WLTC? Explain with less than 150 words (2 points)

*your answer here*