CHALMERS

Examination
Electric and Hybrid Vehicles

TME095 Electric and Hybrid Vehicles

19 March 2021

Grading:

Explain your reasoning and always specify units in your answers when possible.

All relevant answers should be well motivated through step by step calculations showing how you reach the result.

A correct answer which is not sufficiently motivated will result in a reduced score (and in most cases zero points).

To pass the exam 40% is needed (17 out of 42).
17-25.0 points correspond to grade 3
25.5-33.0 points correspond to grade 4
33.5-42 points correspond to grade 5
The result is 60 % of the final course grade.

Review: 19 April. 2021, 12.00-13.00, at CaPS/M2
20 April. 2021, 12.00-13.00, at CaPS/M2

Göteborg, March 2021

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Hybrid vehicles

1) A vehicle is traveling along a flat road at its rated top speed of 200 km/h. Explain and contrast the longitudinal forces acting on the vehicle in the following situations: (1) an environment with still air; (2) an environment with a 20 km/h tailwind; (3) an environment with a 20 km/h headwind. (2 p)

2) A roadway with a steady incline gains 24 meters of elevation per kilometer. Express this road incline: (1) as an angle in degrees, and (2) as a road grade percentage. Show and explain your work. (2 p)

3) Vehicle speed can be described as a function which depends on the sum of forces acting on a vehicle, F_{total}. In this context, explain the vehicle circumstances and discuss the typical control actions in each of the following modes: (1) when F_{total} is greater than zero; (2) when F_{total} is less than zero; (3) when F_{total} is equal to zero. (2 p)

Subsystems

4) Explain how the speed of an induction motor can be controlled when used as a traction motor in an electrified powertrain. (2 p)

5) Discuss the advantages and disadvantages of including more gears in a powertrain transmission. Why are 5 gear transmissions popular on many IC engine couplings while electric motors are often coupled with fewer gears? (2 p)

6) Explain and discuss (at least 3) challenges for automotive battery systems which motivate the use of smaller batteries in hybrid vehicles. (2 p)

Modelling

7) In a quasi-static analysis we divide the simulation into discrete time intervals and assume velocity and acceleration are constant within each of these equally spaced time-steps. What are the drawbacks of making these simulation time steps very small? (2 p)

8) Are the computational operations in our quasi-static simulations of fuel consumption independent from one time-step to the next? Explain why or why not. (2 p)

Some useful equations for the vehicle forces:

$$F_{drag} = c_d \cdot \frac{1}{2} \cdot \rho_{air} \cdot A_f \cdot v^2 + c_r \cdot m_v \cdot g \cdot \cos(\alpha) + m_v \cdot g \cdot \sin(\alpha)$$

$$m_v \cdot a = F_{traction} - F_{drag}$$

Density of the air = 1.25 kg/m^3

9) Powertrain requirements

An EV has the following vehicle data:

• Total vehicle mass	1200 kg
• Front area	2.0 m2
• Wheel radius	0.25 m
• Rolling resistance coefficient	0.01
• Aerodynamic drag coefficient	0.25

Electric machine and driveline data:

• Maximum torque	200 Nm
• Nominal speed	300 rad/s
• Maximum speed	1200 rad/s
• Gear ratio	8

The powertrain is an electric machine connected to the wheels with a fixed gear ratio.

Assume a lossless driveline and lossless electric machine.

a) Calculate the maximum and minimum traction force the power train can produce on the vehicle and plot them in a Force vs. Speed diagram for all positive speeds.

(1p)

The EV initially drives at 80 km/h on a flat road. The vehicle then accelerates with a constant acceleration of +0.5 m/s^2 up to a speed of 120 km/h, at which point the acceleration stops and the vehicle continues to drive at 120 km/h.

b) Calculate how high shaft torque the electric machine needs to produce to accelerate +0.5 m/s^2 at 80 km/h. (2p)

c) Plot the force-speed trajectory in a diagram showing how the longitudinal traction force from the wheels varies when

first driving in 80 km/h,

then accelerating as described above and

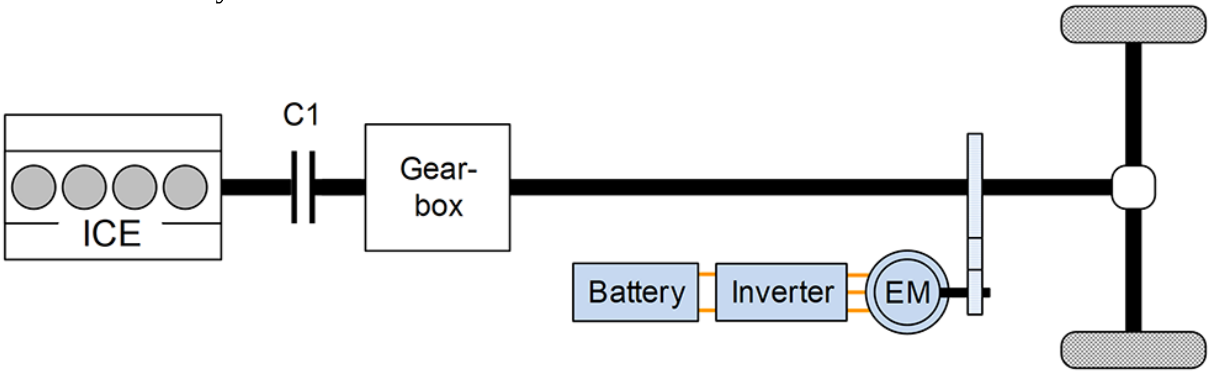
then driving at constant speed at 120 km/h (on a flat road, for this specific vehicle).

(2p)

10) Parallel hybrid powertrain

A parallel hybrid has the powertrain shown in the figure below. It has the following data:

- Allowed engine speed range 900-6000 rpm
- Maximum Torque 215 Nm at 3500 rpm
- Final gear ratio 3
- Wheel radius 0.3 m
- Gear ratios from first to fifth gear (engine shaft speed/output shaft)
  3 2 1.5 1 0.8
- Gear ratio from electric machine shaft to wheels
  10
- Efficiency of transmission is assumed to be 100%



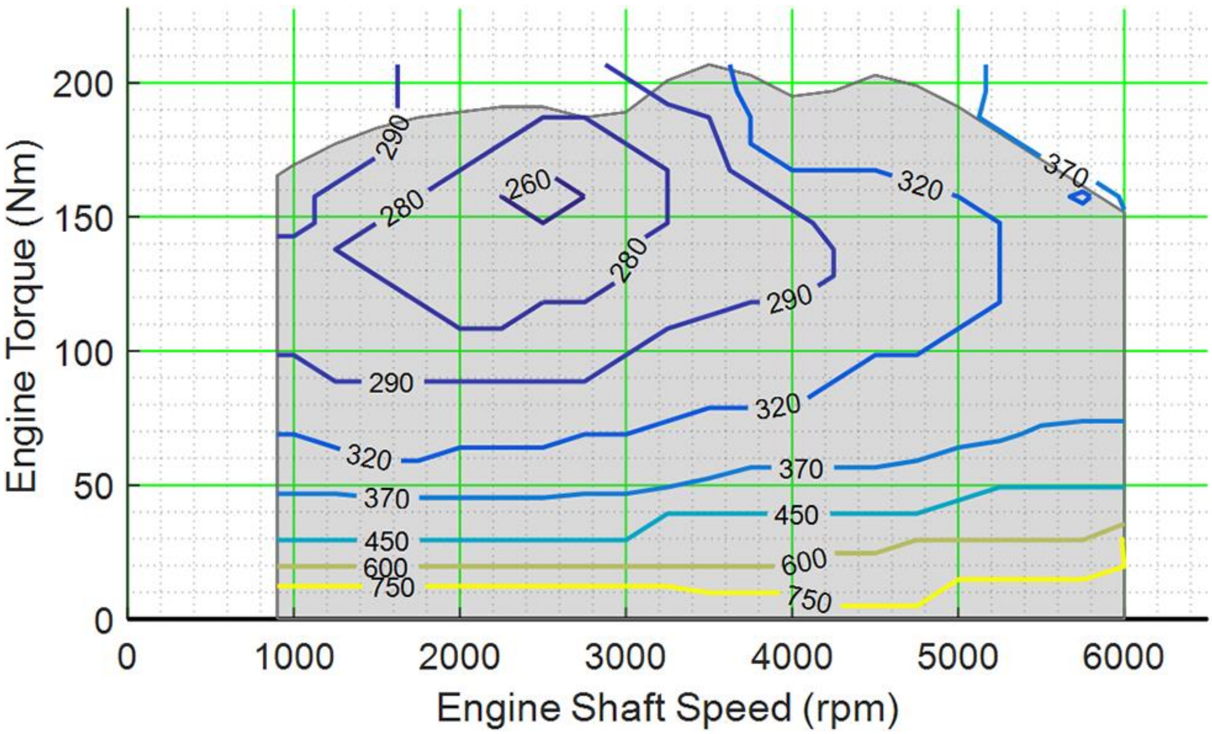


Diagram above: Fuel consumption (bsfc [g/kWh]) as a function of the engine (ICE) speed and torque.

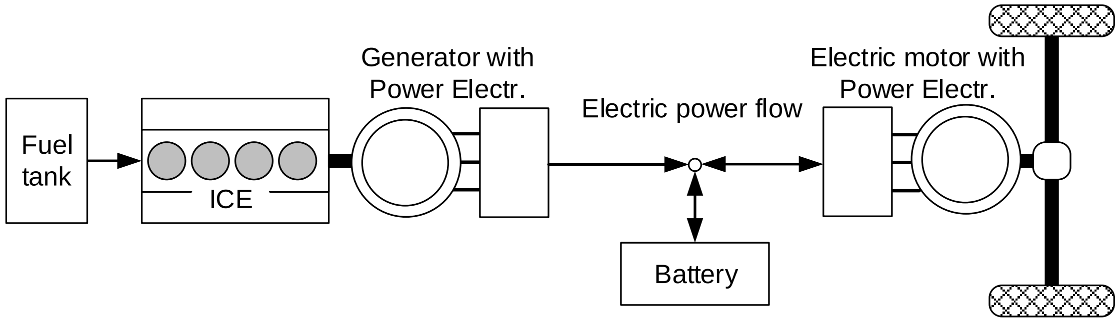
While driving at 90 km/h the vehicle traction force is given as 400 N and the EM shaft torque is 0 Nm.

a) Which gear leads to the lowest fuel consumption?
- On that gear, what is the engine torque and engine speed, and what is the engines BSFC then? (2p)

For the same driving situation, 90 km/h and 400N traction force, the EM is now charging the battery with 53 kW. The EM torque is given as -70 Nm.

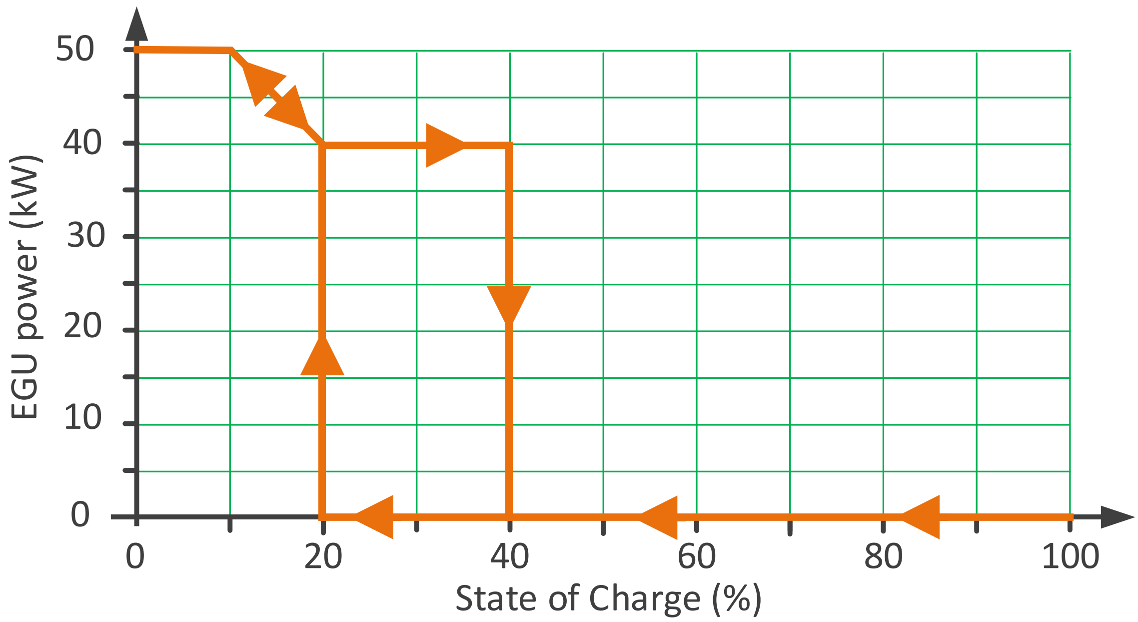
b) Which gear leads to the lowest fuel consumption now?
- On that gear, what is the engine torque and engine speed, and what is the engines BSFC then? (3p)

11) Series hybrid control

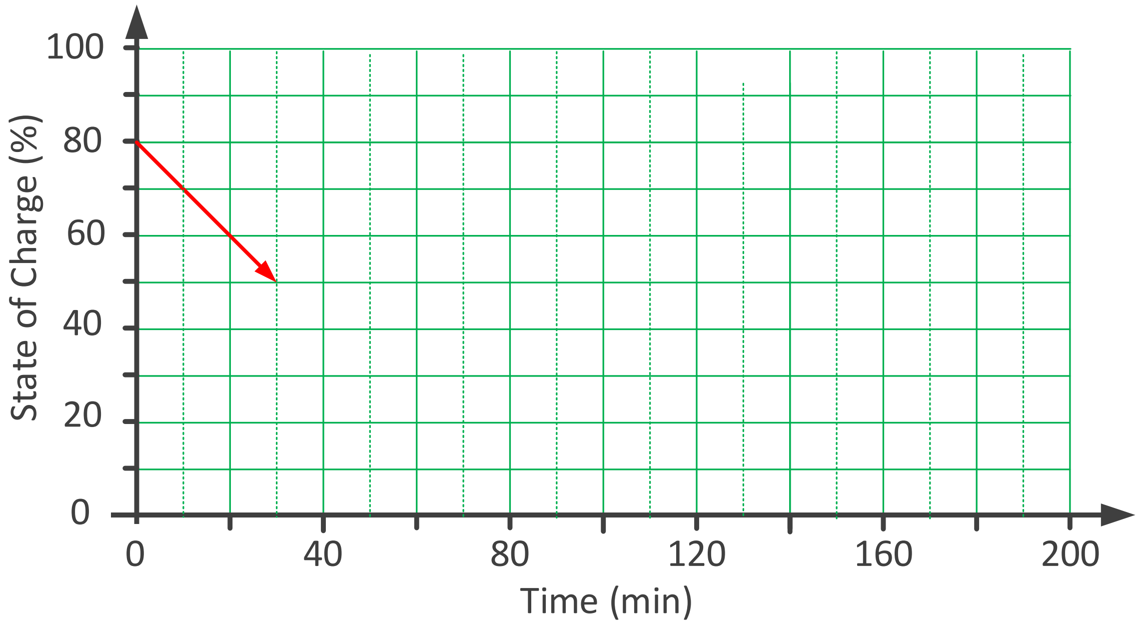


Maximum traction motor power	150 kW
Battery capacity	50 kWh
Max power generated by the Range Extender	50 kW

The Range extender controller follows the strategy shown in the diagram below



The vehicle starts a trip with 80% SoC and Range Extender Off. The Battery SoC follows the red curve in the below diagram for the first 30 minutes of the trip.



a) What power does the traction motor draw from the DC link? (1p)

If the power drawn by the traction motor is constant:

b) Continue the curve showing the battery SoC as function of time from all the way 200 min in a diagram with SoC versus time. (3p)

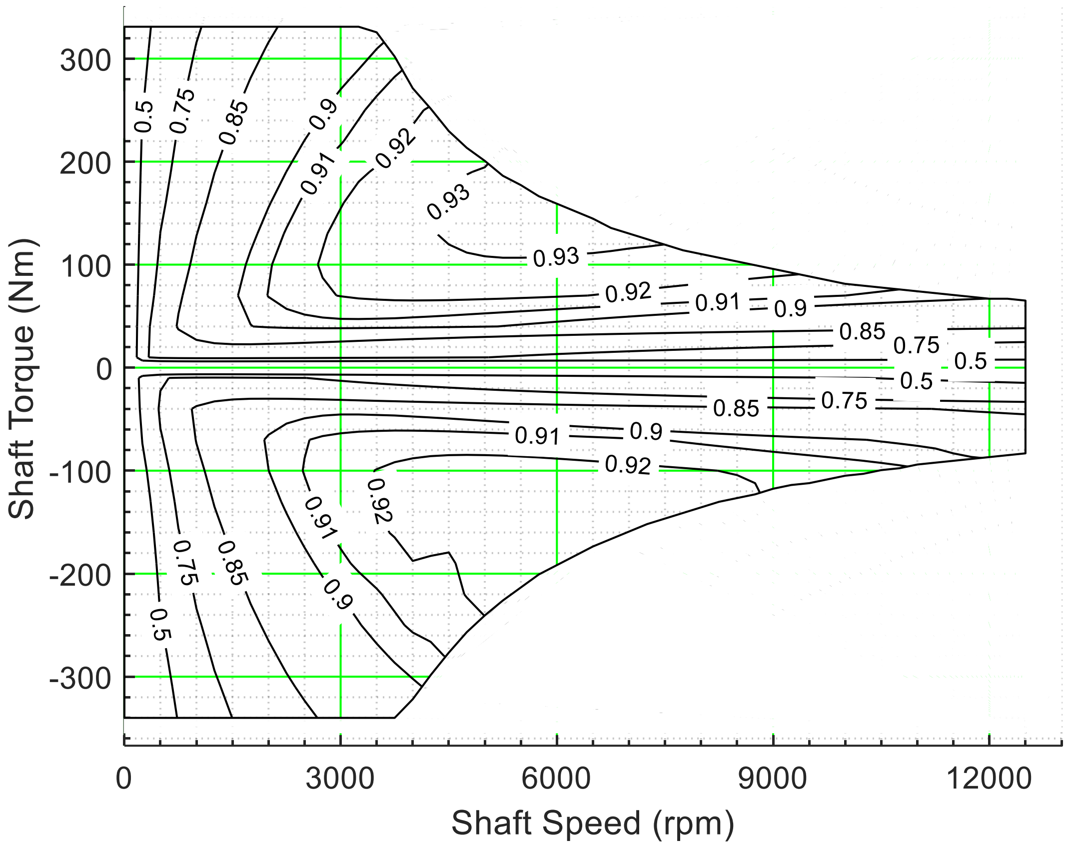
(For full points your diagram must be accompanied by calculations of how the SoC changes and motivations explaining why the SoC curve changes behavior a few times during the trip)

c) Describe another driving situation which, for this vehicle, can result in a battery SoC of 5%, and explain what made the SoC drop so low. (1p)

12) Battery electric powertrain design

A battery electric vehicle shall use an existing electric traction motor with inverter. The motor with inverter has the operating range and combined efficiency shown below, and the vehicle shall have the following performance/component data.

- Vehicle top speed — 125 km/h
- Wheel radius — 0.3 m
- Efficiency from EM shaft to road — 100%



a) What gear ratio should be used from electric machine shaft to wheels in order to maximize the traction force of the powertrain at take-off from standstill (0 km/h)? (1p)

b) How high is the power drawn from the battery when the vehicle drives 30 km/h and requires a traction power of +6000 N? (2p)

c) What is the maximum power the battery can be charged with in regeneration mode if the vehicle speed is 105 km/h? (2p)

Powertrain design

(For the following questions you are expected to ***define the desired properties of the vehicle*** *and then* ***propose and explain a solution****.*

13) A recent concept car from a German automaker demonstrates a battery electric vehicle for off-road sport driving in sandy terrain. The proposed design uses a 150 kWh electric motor with a single speed transmission and claims a range of 250 km (as measured on the WLTP cycle). What advantages would this design have over older IC engine powered "dune buggy" concepts that are often favored in loose sand environments? How would you design a competing hybrid vehicle in order to offer advantages of both the BEV and ICE designs? (3 p)

14) Quebec City, Canada has an average annual snowfall of 124 inches and record-breaking winter temperatures of -36 degrees C. What kind of vehicle design would you propose to work reliably for city driving (around town and to and from work) and also offer a range greater than 500 km under these adverse weather conditions? (3 p)