Final Exam in the course ”Hybrid Electric Drives” at LTH

Location:	??? @ LTH	
Means of assistance:	Calculator	
Grades:	20-30 p:	3
	31-40 p:	4
	41-50 p:	5

1 Energy consumption

a. A modern small gasoline car consumes as low as 0.35 litre of gasoline/10 km in mixed traffic. How much of this energy, expressed in [kWh/10km], do you estimate reaches the wheels? Your answer should include your assumption of average efficiency? (3p)

*Assuming an average efficiency of 25 % in the combustion engine and 10 kWh/litre of gasoline, then 0.25*10*0.35 = 0.88 kWh/10km should reach the wheels, not accounting for transmission losses.*

b. How much energy would the same car in an electric version need to consume from the charging outlet, to provide the same performance? Your answer should include realistic assumptions on efficiencies! (3p)

Assume 95 % Charging efficiency, 95 % Discharging efficiency, 90 % electric traction drive efficiency, then the electric version would need 0.88/(0.95x0.95x0.9)=1.1 kWh/10km.

c. What is roughly the efficiency of a Conventional 12 V generator and of a DC/DC converter from 300 V to 12 V? (1p)

Generator: 50…70 %

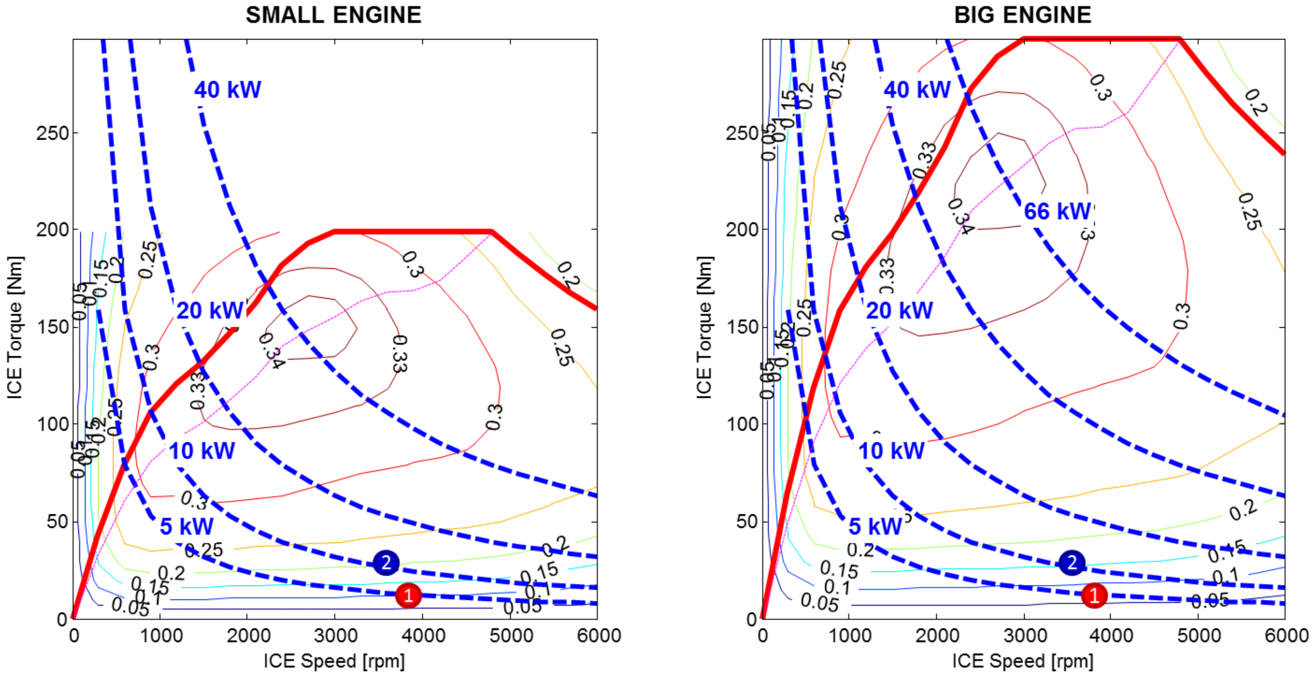
DC/DC: >90 %, even > 95 % is possible

d. A change from filament lamps to LED lamps is on-going, even in vehicles. Assume that 300 W of lamp loads is replaced with LED based technology in a conventional car, using only 30 W of electric power instead. How much fuel consumption reduction does that correspond to in 50 km/h. (3p)

Assume 50 % generator efficiency, i.e. saving 270/0.5 = 540 Watt mechanical power from the combustion engine. Assume then 25 % ICE efficiency, i.e 540/0.25=2160 W fuel power to the ICE. Assume finally 10 kWh/litre fuel energy density, i.e. 2.160/10 litre/hour, i.e. – solved for 1 hour driving = 2.160/5/10 [kWh]/[x10km]/[kWh/liter]= 0.043 litre/10 km.

2 Hybridisation, potential

The figure below shows the efficiency maps of two gasoline engines. In both diagrams the maximum torque (**RED** wide line), three power lines (**BLUE** dashed lines), the optimal operating point line (MAGENTA) and finally two operating points as circles in **RED(1)**, **BLUE(2)** .



a. What will be the **fuel consumption** of two identical conventional cars, one equipped with the SMALL ENGINE and one with the BIG ENGINE if they run at 50 km/h in city traffic at 5 kW traction power if they both try to use the RED(1) operating point? All other traction components have 100 % efficiency. Assume a fuel energy density 10 kWh/litre. (1p)

SMALL ENGINE: 10 % efficiency -> 50 kW fuel power = 50 kWh/h = 5 litres/h. With 50 km/h the fuel consumption is 5/50 litres/km = 1 litre/10km.

BIG ENGINE: 7.5 % efficiency -> 67 kW fuel power = 67 kWh/h = 6.7 litres/h. With 50 km/h the fuel consumption is 6.7/50 litres/km = 1.33 litre/10km.

b. In the cars in the previous question, **how much and with what means** could you improve the fuel consumption for the two cars above when driving in city traffic at 5 kW traction power compared to the **RED(1)** operating point? You are allowed to use operating points with speeds higher than 1300 rpm. (2p)

SMALL ENGINE: By shifting to a higher gear we can get from 10 % efficiency to 25 % efficiency, i.e. reduce fuel consumption by 25/10=2.5 times.

BIG ENGINE: By shifting to a higher gear we can get from 7.5 % efficiency to 20 % efficiency, i.e. reduce fuel consumption by 20/7.5 =2.67 times

c. If we assume that both cars above are hybrid cars, **how much and with what means** could you improve the fuel consumption when driving in 70 km/h on a country road at 10 kW traction power compared to the **BLUE(2)** operating point? You are allowed to use operating points with speeds higher than 1300 rpm. All other traction system components, including the electrical drive and the battery, have 100 % energy efficiency.

You answer should include how much OR for how long time you use the battery! (3p)

SMALL ENGINE: 20 % efficiency -> 50 kW fuel power = 50 kWh/h = 5 litres/h. With 70 km/h the fuel consumption is 5/70 litres/km = 0.71 litre/10km. By selecting the best operating point (34 % efficiency @ 40 kW) for a while (10/40 parts of the time) and then charge the battery with 30 kW and drive the vehicle with 10 kW, the average fuel consumption will be reduced by 34%/20% times=1.7 times, i.e. from 0.71 litres/10 km to 0.71/1.7=0.42 litres/10 km. The rest of the time the vehicle runs in full electric mode.

BIG ENGINE: 15 % efficiency -> 66 kW fuel power = 66 kWh/h = 6.6 litres/h. With 70 km/h the fuel consumption is 6.6/70 litres/km = 0.94 litre/10km. By selecting the best operating point (34 % efficiency @ 66 kW) for a while (10/66 parts of the time) and then charge the battery with 30 kW and drive the vehicle with 10 kW, the average fuel consumption will be reduced by 34%/15% times=2.27 times, i.e. from 0.94 litres/10 km to 0.94/2.27=0.42 litres/10 km. The rest of the time the vehicle runs in full electric mode.

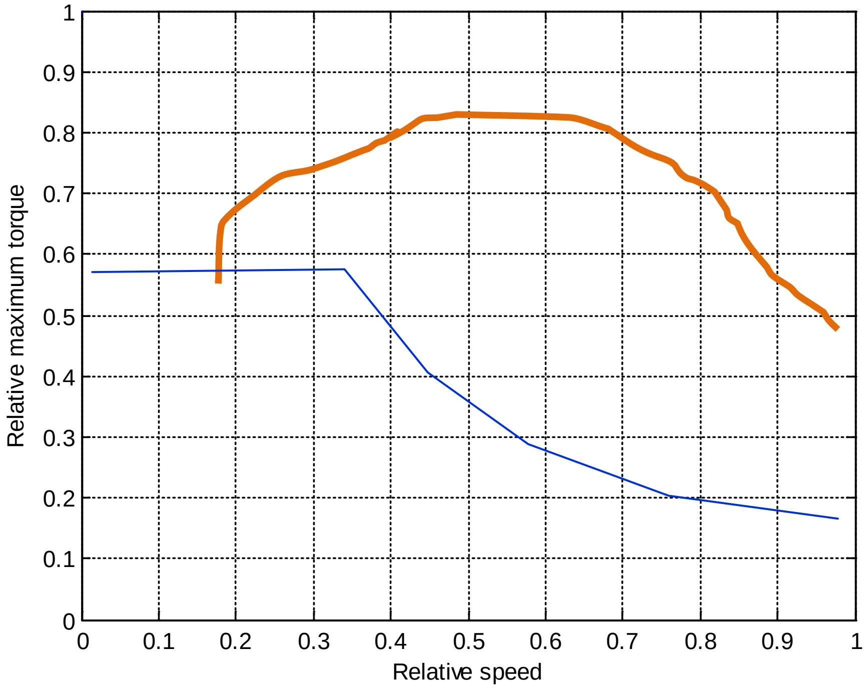
d. A Hybrid Car can have either a Parallel or a Series hybrid system. Make a rough design of the two traction systems assuming that the maximum wheel power is 100 kW in both alternatives (1p). Explain **clearly** your choice of proportions between the ICE and the electrical machines in both cases (3p). (4p)

***Series**: ice/gen/trac = 20/25/100 kW, roughly. The traction machine is 100 kW since that is required. The combustion engine is 20 kW since that is enough for highway traffic with a car. The generator is 25 kW to be able to control the speed of the ICE (it has to be a bit stronger than the ICE).*

***Parallel**: ice/EM = 80/20 kW, roughly. The EM is 20 kW since about 15…25% of the total traction power is enough in a parallel hybrid to achieve a significant fuel consumption reduction. The ICE is 80 kW to give 100 kW in total.*

3 Hybridisation components

a. A combustion engine and an electrical machine are said to match well in terms of torque capabilities in a parallel hybrid electric drive train. Draw realistic maximum torque limitations in the diagram below and explain in your own words why these two machine types match so well. The Field Weakening Ratio of the electric drive should be 1:3. (3p)



b. Roughly how high is the peak efficiency of the electrical traction machine for a hybrid vehicle, and of the corresponding power electronic converter? (2p)

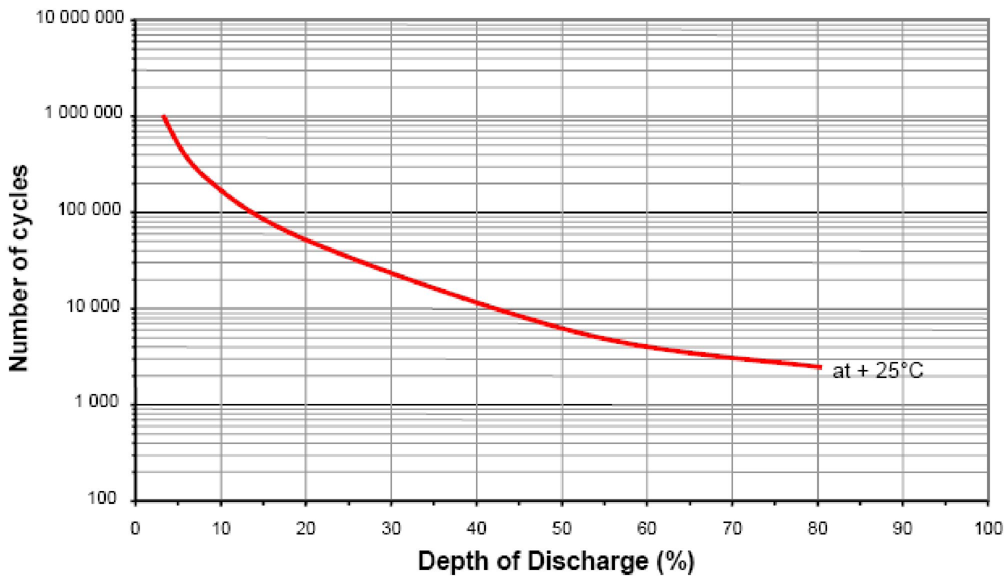
95 %, for the traction machine and 98 % for the power electronic converter

c. An electric BUS in city traffic needs about 15 kWh/10 km of electric energy from the electric power grid. What is roughly the battery weight and maximum battery power for a battery that can take the bus 10 km? Express your assumptions on the use of the battery in terms of DoD. (2p)

Assume 50 % DoD and 0.1 kWh/kg energy density. 10 km -> 15 kWh. 50 % DoD -> 30 kWh. 0.1 kWh/kg -> 300 kg. With 1 kWh/kg also 300 kW.

d. Two identical electric vehicles starts the same trip with full batteries. Vehicle A runs the battery down to 40 % SOC and then recharges. Vehicle B runs down to 90 % SOC and then recharges. Which of the two vehicles will last the longest distance before the batteries end of life? Motivate! (3p)

*With 60 % DoD the lifetime may be 4000 cycles. With 10 % DoD the lifetime may be 200000 cycles. Thus the total converted energy will be 10*200000/(60*4000) = more than 8 times higher for the one that recharges more frequently.*



4 Charging

a. With how high powers do we normally supply energy to a conventional car? Make your own REASONABLE assumptions! (1p)

*Lets say that we fill 500 km of driving range in 3 minutes. With 0.6 litre/10km of fuel consumption and 10 kWh/litre, this corresponds to a power of (500*0.6/10*10/(3/60)) =* ***6 MegaWatt****.*

b. With your own assumptions on the average energy efficiency of a combustion driven vehicle and an electrically driven vehicle, discuss the realism of supplying energy to electric vehicles in a similar way (seldom, and in a short time) as to conventional vehicles. (1p)

*Assume 85 % efficiency of an electric vehicle and 25 % of a combustion vehicle, the energy consumption and thereby the charging power would be reduced by 25/85 times, i.e. the charging power drop from 6 MW to 6*25/85=***1.8 MW***. This is still impossible from an electrical point of view. There are no manual or automatic connectors suitable for a car that can transfer 1.8 MW. Thus, much lower charging power has to be accepted and thus much longer charging times are needed.*

c. Will significantly increased energy density in batteries improve this situation?(1p)

No*, the energy density of the battery does not change the fact that extreme charging powers are needed to supply energy to electrical vehicles in a similar way as to conventional vehicles.*

d. To drive really long distances, like a 1000 km holiday trip to the alps for skiing, with a full electric vehicle is a bit of a challenge. Assume a charging power of 120 kW (as with Tesla's SuperCharger) and an average traction power of 20 kW at highway speed of 100 km/h in average and a battery range of 200 km. How much longer will the trip be with a full electric vehicle compared to a conventional (combustion only) vehicle? Account for 60 minutes brake every 4 hours of driving with a conventional car. (3p)

Conventional*: 1000 km/100km/h = 10 hours + 2x60 minutes break every 4 hours = 12 hours trip in total.*

__Electric__: 1000 km/100km/h = 10 hours of pure driving. 200 km range takes 2 hours to drive and thus 40 kWh of energy, which is supplied in 0.33 hours or 20 minutes when charging at 120 kW. Thus every two hours a break of 20 minutes is needed for charging. That means 5x20 minutes = 100 minutes = 1 hour 40 minutes in total charging time for the 1000 km trip. The total trip time is thus 11h 40minutes, which is __comparable to the conventional vehicle trip__.

e. Assume that the vehicle in the previous example instead of batteries for 200 km range has batteries for only 50 km range AND instead has an ability to charge from electric roads. Assume also a battery system cost of 2000 SEK/kWh, 4 million cars in Sweden with 1.5 kWh/10km energy consumption and 15000 km National and European road in Sweden. How expensive can an electric road be per kilometer be based on the reduce battery cost? (2p)

Assume a 50 % DoD use of the batteries. 4000000 cars x 150 km range x 0.15 kWh/km x 2000 SEK/kWh / 0.5 / 15000 km = 24 Million/km ! This is in the same range as most cost estimates on electric road construction.

f. Sweden use about 80 TWh of fuel energy for our conventional vehicle fleet and would need about 25 TWh of electric energy if the whole vehicle fleet was full electric. With an energy price of 1 SEK/kWh, true both for electricity and fossil fuel, how much could an electric National and European road system cost per kilometre to break even between an all-electric and a conventional vehicle fleet in a 10 year period? (2p)

(80-25) TWh x 1e9 SEK/TWh x 10 years/ 15000 km = 36.7 MSEK/km. This is in the same range as most cost estimates on electric road construction.

Auxiliaries and EMC

g. Why cannot all electric loads on a vehicle, including the traction system if it is a hybrid vehicle, be run from the 12 V supply? (3p)

To high currents at powers of 10's of kW

h. Name at least three conventional auxiliary loads that could benefit from being converted from mechanical drive (belt) to electrical drive, and the type of benefit. (4p)

Water pump, air conditioning compressor, servo steering pump. All benefit on increased efficiency and simplified vehicle constructions.

i. An EV with a 600 V traction drive is standing in a test rig and running the electric traction drive at very low speed. You know that an electric drive requires a voltage that is almost proportional to the speed. Is it safe to touch the electric terminals of the power supply to the traction drive? Motivate your answer! (3p)

NO! The output voltage is PWM-controlled and even though the speed is low and thus the average voltage may be low, the instantaneous voltage may still be high.