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

Fall 2012

Questions to Mats Alaküla and/or Zhe Huang

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

1 Energy consumption

a. The MAXIMUM efficiency of a Diesel and a Gasoline engine is about 44 % and 33 % respectively. What is the AVERAGE efficiency of a diesel truck on the highway and of a gasoline driven car in city traffic, both conventional non-hybrids? (2p)

- about 40 % in the truck and 10 % in the car. I want the students to indicate that they understand that a truck on the highway operate near maximum efficiency but a car at low efficiency. The exact figures are less important.

b. Same as previous question, but now with hybrid vehicles? (3p)

- about 40 % in the truck and 30 % in the car. I want the students to indicate that they understand that the truck will not be significantly helped by hybridisation, but the car will. The exact figures are less important.

c. Assume that a car in city traffic need 5 kW of average tractive power, and that the load on the 12 V system is 1 kW. Which of these power consumptions has the biggest influence on the fuel consumption, and why? (2p)

- The propulsion system, the 12 V system need about 2 kW due to a low efficiency of the generator

d. What is roughly the efficiency of a DC/DC converter from 300 V to 12 V? (3p)

- over 90 %, probably over 95%.

2 Hybridisation, potential

a. Which are the <u>two</u> main reasons why electric hybridisation of a combustion engine driven vehicle reduces the fuel consumption? (2p)

- 1: Adaptation of the combustion engine operating point, 2: Regeneration of brake energy.

b. A hybrid City Bus can have either a parallel or series hybrid system. Make a rough design of the two traction systems assuming that the maximum wheel power is 200 kW in both alternatives. (2p)

- *series: ice/gen/trac = 50/60/200 kW, roughly*
- *parallel: ice/trac = 150/50 kW, roughly*

c. Which of these vehicles is likely to have the highest system cost (1p)

- the series due to more total installed power converters

d. Which of these buses is likely to have the lowest fuel consumption in a traffic flow with many stops and starts? (1p)

- *The series, due higher electric wheel power, useful in frequent regeneration*

e. Which of these vehicles will have the lowest fuels consumption on the highway?(1p)

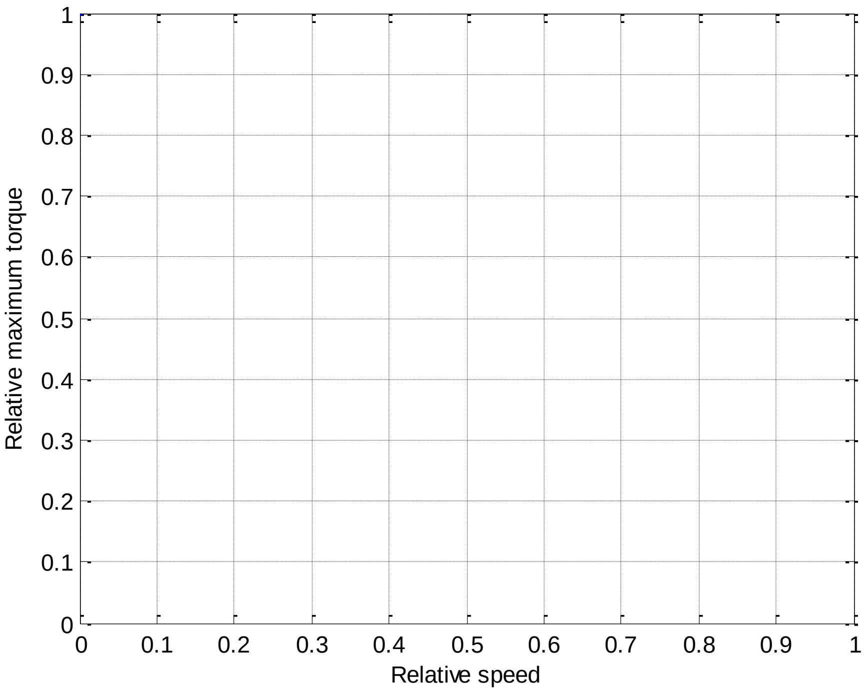
- *The parallel, due fewer energy conversions*

f. A NON-hybrid vehicle runs with the average diesel energy conversion efficiency 22 %. If hybridised, what is the highest fuel consumption reduction that a good design could lead to? Assume that all other involved components (transmission, electric drive, battery) are ideal (have no losses). (3p)

- *The answer is 50 % fuel consumption reduction, since the average efficiency can be increased to 44 % (max of a diesel), i.e. doubled, i.e. fuel consumption halved.*

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. Use a field weakening factor of four for the electrical drive. Explain in your own words why these two machine types match so well. (3p)



b. A combustion driven long haul truck supply about 300 kW of chemical power (as diesel, from the tank) to drive the vehicle along the highway on flat ground. How much of this chemical power reaches the wheels? How much electric power would a full electric version of the same vehicle consume from the battery in the same operation? (2p)

- *about 40 % reaches the wheels, i.e. 120kW. The electric version would consume about 140 kW.*

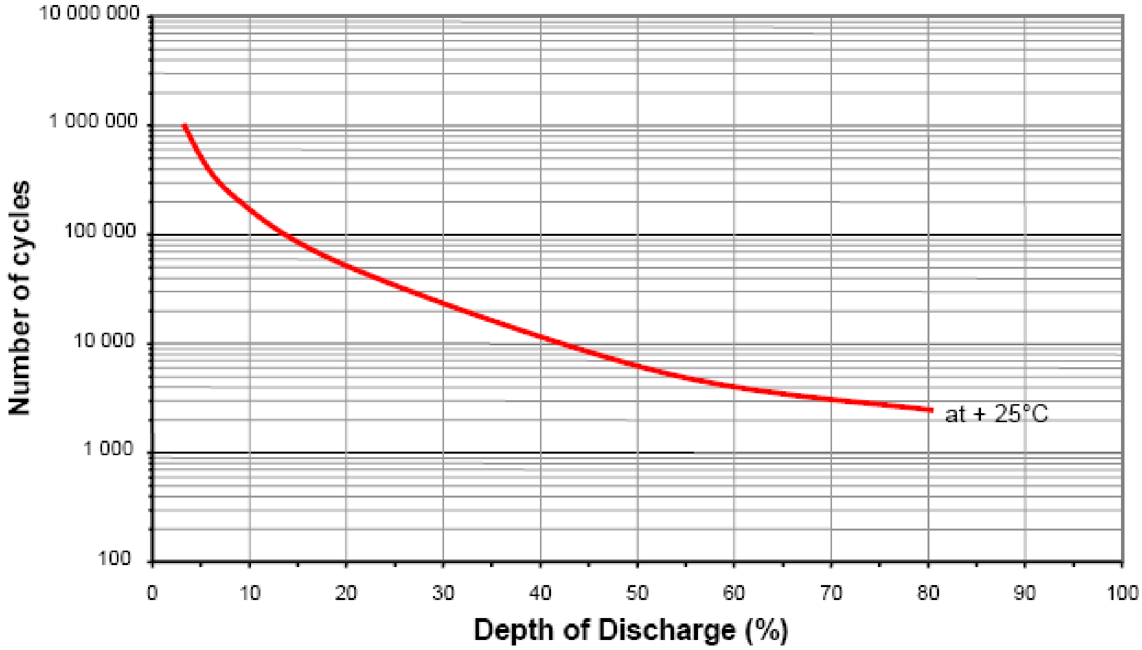
c. A Cessna Centurion (a small propeller driven aircraft) has a 224 kW combustion engine that runs at 135 kW average power in flight (306 km/h), a 250 litre gasoline tank and a take off weight of 1724 kg.

If it was to be made electric, how big batteries would it need to bring along the same energy as the combustion version and what would be the weight of the vehicle? (2p)

- *250 litre gasoline = 2500 kWh = 2500/0.1 kg = 25000 kg >> take of weight. The student could (better) account for the higher conversion efficiency of the electric air craft and thus bring less batteries, but the result would still be devastating.*

d. The cycle life of a lithium ion battery is highly non-linear with respect to cycle depth. Assume a full electric vehicle that always runs the same trip before recharging, corresponding to a 60 % DoD. How much will the operational battery cost (e.g. SEK/km) change if a two times bigger (in terms of energy storage capability) battery is installed? Motivate! (3p)

-With 60 % DoD the lifetime may be 4000 cycles. A doubled battery size costs twice as much, but will have a 30 % DoD in the same cycle and thus last about 25000 cycles. The doubled battery cost is thus spread on about six (25000/4000) times more cycles, i.e. the operational cost is reduced three times!



4 Charging

We are used to "charging" (= filling the tank of) conventional cars in very short time, assume 3 minutes to provide 500 km of driving range.

a. Discuss the realism of reaching the same range on one full charge with an equivalent electric vehicle. (2p)

- 500 km = 100 kWh used energy = 200 kWh battery energy = > 2000 kg of batteries = not realistic compared to vehicle weight.

b. Discuss the possible charging time needed for an equivalent electric vehicle, with the same range. (3p)

- 100 kWh/3 minutes = 100 kWh/0.05 h = 2000 kW = not realistic – no manually connected supply would provide that power and the battery would not accept it. A more realistic charging time is being connected to a few 10's of kW charging power and thus the charging will still take about one hour.

c. Plug In can be arranged either as conductively or inductively connected. Assume 100 % efficiency of a conductively connected charger but 90 % on an inductively connected charger. For a customer buying a full electric vehicle and charging it from an inductive charger, what is the additional cost for the additional charging losses only if the vehicle lasts for 200 000 km . (2p)

-200 000 km x 0.2 kWh/km x 10 % additional losses= 4 000 kWh = 4 000 SEK c:a.

d. The battery is usually regarded as the weak point in electric hybridization of vehicles. With your assumptions on power and energy densities and a battery cost of 5000 SEK/kWh, what would be a suitable size of a battery for a "plug in" hybrid bus (using 2 kWh/km in EV mode) that should be able to drive at least 20 km on pure electric drive in mixed city/highway traffic, using your own assumption on electric energy consumption in kWh/km? The answer should include your assumptions of DOD, cycle life estimation and combined energy and battery cost per 10 km. (3p)

*- 20 km = 40 kWh DoD = 80 kWh battery (@50%DoD) = at least 6000 cycles lifetime. 6000*20 km = 120 000 km life -> 5000 SEK/kWh*80 kWh/120000 km = 3.3 SEK/km battery cost. Energy use is 2 kWh/km = about 2 SEK/km.*

5 Auxiliaries and EMC

a. 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

b. 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.

c. 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.*