Setup

```
In[ ]:= << QSSutils`
<< Adhoc`
```

TME095 — final exam (1) — 2021

Hybrid vehicles

1. (2p)

A vehicle 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 these three 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.

The difference in each case is the air motion around the vehicle which is moving at its top speed. In case 1, moving through still air, the top speed is 200 km/h. Here the acceleration equals the rolling resistance and drag forces. In case 2 (tailwind), max speed should be slightly more than 200 km/m, since the relative air motion implies a reduced speed in the drag force calculation. In case3 (headwind), the opposite is true--drag force increases due to the relative motion and the top speed is less than 200 km/h.

```
In[ ]:= ClearAll["vdata", "m", "Af", "r", "cr", "cd"];
Module[
 {vdata = Association @makeRules[$tractionForceVehicleKeys , {m, Af, r, cr, cd}]},
 Echo[fAero[vdata, (200 * 1000./(60 * 60)), Verbose → True], "Case 1 (still air): "];
 Echo[fAero[vdata, (200 - 20) * 1000/(60 * 60)], "Case 2 (tailwind): "];
 Echo[fAero[vdata, (200 + 20) * 1000/(60 * 60)], "Case 3 (headwind): "];]
```

$c_d \cdot \frac{1}{2} \cdot \rho_{air} \cdot A_f \cdot u^2$ = 1929.01 Af cd newtons

» Case 1 (still air): 1929.01 Af cd

» Case 2 (tailwind): 1562.5 Af cd

» Case 3 (headwind): 2334.1 Af cd

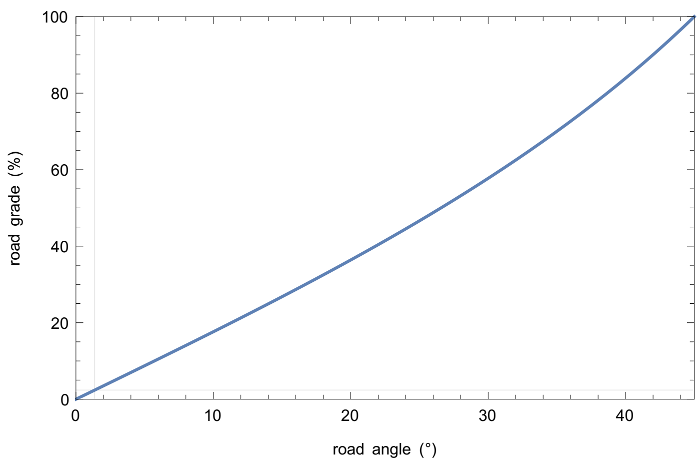
2. (2p)

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 percentage grade. Show/explain your work.

In[ ]:=
```
roadGrade[24., 1000, Verbose → True];
```

```
1.37° incline : Tan[0.0240] = 2.4% grade
```

In[ ]:=
```
Module[{rise = 24, run = 1000, grade = 2.4},
 Plot[100. * Tan[x * π/180], {x, 0, 45},
  PlotRange → {{0, 45}, {0, 100}}, GridLines → {{180/π rise / run}, {grade}},
  Frame → True, FrameLabel → {"road angle (°)", "road grade (%)"}]]
```

Out[ ]=


3. (2p)

Vehicle speed can be described as a function which depends on the sum of the forces applied to the vehicle, Ft. In this context, explain the three operating modes (Ft > 0, Ft < 0, and Ft = 0) and discuss the typical control actions or responses in each mode for a hybrid electric vehicle.

See Guzzella, Section 2.1.3.

Subsystems

4. (2p)

Explain how the speed of an induction machine can be controlled in an electrified powertrain.

5. (2p)

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?

6. (2p)

Explain and discuss (at least 3) challenges for automotive battery systems that favor the use of smaller batteries in hybrid vehicles.

Examples:
high cost is primary concern
limited lifetime and durability
packaging and risk management
charging speed linked to current, higher for larger cells

Modeling

7. (2p)

In a quasi-static analysis we divide the simulation time into discrete 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?

8. (2p)

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.

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9. Powertrain requirements

An EV has the following vehicle properties:

```
In[ ]:= (*total vehicle mass in kilograms*)
vMass = 1200;
(*frontal area in square meters*)
vArea = 2;
(*wheel radius in meters*)
vWheelRadius = 0.25;
(*rolling resistance coefficient*)
vRolling = 0.01;
(*aerodynamic drag coefficient*)
vDrag = 0.25;
```

In[ ]:=
```
(*maximum EM torque in N·m*)
τEMmax = 200;
(*nominal EM speed in rad/s*)
ωEM = 300;
(*max EM speed in rad/s*)
ωEMmax = 1200;
(*gear ratio*)
kGear = 8;
```

In[ ]:=
```
(*assemble vehicle data for computations*)
vehicle = <|"mass" → vMass, "area" → vArea, "wheel radius" → vWheelRadius,
   "rolling resistance" → vRolling, "aerodynamic drag" → vDrag|>;
```

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

a) Calculate the maximum and minimum traction force the powertrain can produce on the vehicle and plot them in a Force vs. Speed diagram for all positive speeds. (1p)

In[ ]:=
$$\left(\frac{60*60}{1000}\right) * \omega EMmax * \frac{r}{k} \text{ /. } \{r \to vehicle["wheel radius"], k \to kGear\};$$
```
Echo[Quantity[%, "km/h"], "Max vehicle speed: "];
```

» Max vehicle speed: 135. km/h

In[ ]:=
```
pEMmax = τEMmax * ωEM
```

Out[ ]= 60 000

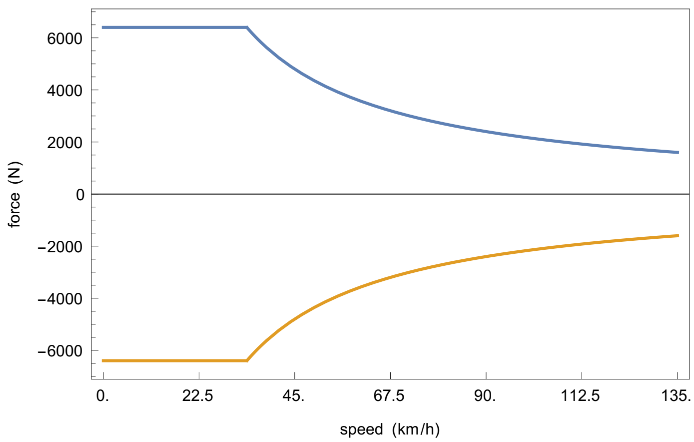
In[ ]:=
$$\tau EM[\omega\_] := Piecewise\left[\left\{\{0, \omega < 0\}, \{\tau EMmax, \omega > 0 \&\& \omega < \omega EM\}, \left\{\frac{\tau EMmax * \omega EM}{\omega}, \omega > 0 \&\& \omega < \omega EMmax\right\}\right\}\right]$$

In[ ]:=
```
τEM[ω]
```

Out[ ]=
$$\begin{cases} 0 & \omega < 0 \\ 200 & \omega > 0 \&\& \omega < 300 \\ \frac{60000}{\omega} & \omega > 0 \&\& \omega < 1200 \\ 0 & True \end{cases}$$

```
In[ ]:= Module[{force, ticks, r = vehicle["wheel radius"], k = kGear},
  ticks = Block[{speed, x = Range[0, 1200, 200]},
    speed[ω_] = (60 * 60 / 1000) * ω * r / k;
    Transpose[{x, (speed[#] &) /@ x}]];
  force[ω_] = τEM[ω] * k / r;
  Plot[{force[ω], -force[ω]}, {ω, 0, ωEMmax},
   Frame → True, FrameLabel → {"speed (km/h)", "force (N)"},
   FrameTicks → {{Automatic, None}, {ticks, None}}]]
```

Out[ ]=



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 until it reaches 120 km/h at which point the acceleration stops and the vehicle continues driving at constant speed.

b) Calculate how high the shaft torque of the electric machine needs to be to produce 0.5 m/s^2 acceleration at a speed of 80 km/h. (2p)

```
In[ ]:= (*speed*)
u = 80. * 1000 / (60 * 60);
Quantity[%, "m/s"]
```

Out[ ]= 22.2222 m/s

```
In[ ]:= (*acceleration*)
a = 0.5;
Quantity[%, "m/s/s"]
```

Out[ ]= 0.5 m/s^2

```
In[ ]:= (*slope*)
α = 0;

In[ ]:= Module[{roll, aero, grav, drag},
    roll = fRoll[vehicle, α, Verbose → True];
    aero = fAero[vehicle, u, Verbose → True];
    grav = fGrav[vehicle, α, Verbose → True];
    fDrag[vehicle, u, α, Verbose → True];
    Echo[Quantity[roll + aero + grav, "Newtons"], "Total drag: "]];
```

$c_r \cdot m \cdot g \cdot \text{Cos}[\alpha] = 117.72$ newtons

$c_d \cdot \frac{1}{2} \cdot \rho_{air} \cdot A_f \cdot u^2 = 154.321$ newtons

$m_v \cdot g \cdot \text{Sin}[\alpha] = 0.$ newtons

$(c_r \cdot m \cdot g \cdot \text{Cos}[\alpha]) + (c_d \cdot \frac{1}{2} \cdot \rho_{air} \cdot A_f \cdot u^2) + (m_v \cdot g \cdot \text{Sin}[\alpha]) = 272.041$ newtons

» Total drag: 272.041 N

```
In[ ]:= fAccel80 = fTrac[vehicle, u, 0, a] - fDrag[vehicle, u, 0];
Echo[Quantity[fAccel80, "N"], "Acc. force @ 80 km/h: "];
```

» Acc. force @ 80 km/h: 600. N

```
In[ ]:= Module[{r = vehicle["wheel radius"], k = kGear, τAccel, τDrag},
    τAccel = fAccel80 * r/k;
    Echo[Quantity[τAccel, "N·m"], "τ_accel = "];
    τDrag = fDrag[vehicle, u, α] * r/k;
    Echo[Quantity[τDrag, "N·m"], "τ_drag = "];
    Echo[Quantity[τAccel + τDrag, "N·m"], "τ_traction = "];]
```

» τ_{accel} = 18.75 m N

» τ_{drag} = 8.50128 m N

» $\tau_{traction}$ = 27.2513 m N

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

first driving at 80 km/h,

then accelerating as described above and

finally driving at constant speed 120 km/h (on a flat road for this specific vehicle). (2p)

You do not have to calculate exact force values for all speeds between 80 and 120 km/h, as long as the curve is correct at 80 and 120 km/h and has a reasonably accurate shape between these speeds.

In[ ]:=
```
fAccel[v_] = Piecewise[
  {{fDrag[vehicle, v 1000./(60*60), α], v < 80}, {fTrac[vehicle, v 1000./(60*60), α, 0.5], 80 < v < 120},
   {fDrag[vehicle, v 1000./(60*60), α], v > 120}}]
```

Out[ ]=

$$\begin{cases} 117.72 + 0.0241127\, v^2 & v < 80 \\ 717.72 + 0.0241127\, v^2 & 80 < v < 120 \\ 117.72 + 0.0241127\, v^2 & v > 120 \\ 0 & \text{True} \end{cases}$$

In[ ]:=
```
fTrac[vehicle, 80 * 1000./(60*60), 0, 0.5, Verbose → True];
Echo[%, "Force to accelerate @ 80 km/h: "];
```

$(c_r \cdot m \cdot g \cdot Cos[\alpha]) + (c_d \cdot \frac{1}{2} \cdot \rho_{air} \cdot A_f \cdot u^2) + (m_v \cdot g \cdot Sin[\alpha]) + m_v \cdot a = 872.041$ newtons

» Force to accelerate @ 80 km/h: 872.041

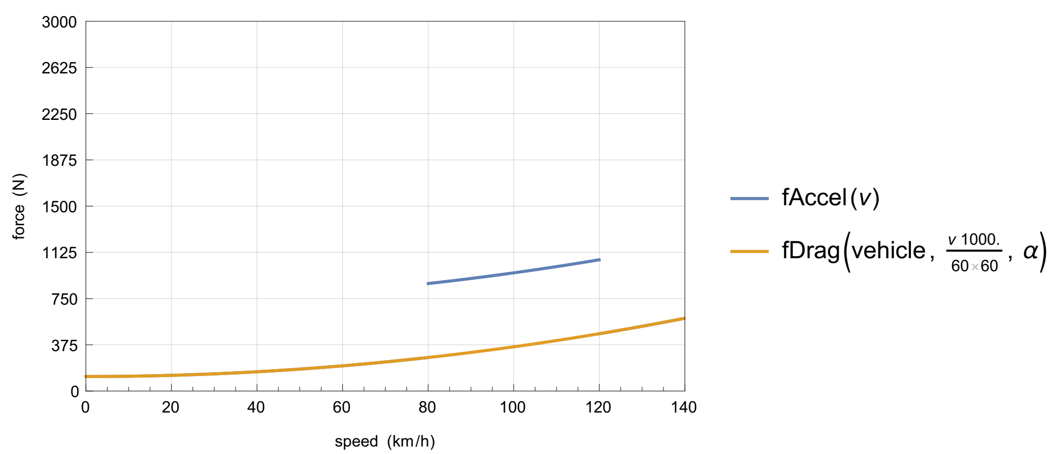
In[ ]:=
```
fTrac[vehicle, 120 * 1000./(60*60), 0, 0.5, Verbose → True];
Echo[%, "Force to accelerate @ 120 km/h: "];
```

$(c_r \cdot m \cdot g \cdot Cos[\alpha]) + (c_d \cdot \frac{1}{2} \cdot \rho_{air} \cdot A_f \cdot u^2) + (m_v \cdot g \cdot Sin[\alpha]) + m_v \cdot a = 1064.94$ newtons

» Force to accelerate @ 120 km/h: 1064.94

In[ ]:=
```
Plot[{fAccel[v], fDrag[vehicle, v 1000./(60*60), α]},
 {v, 0, 140}, PlotRange → {{0, 140}, {0, 3000}}, Frame → True,
 FrameLabel → {"speed (km/h)", "force (N)"}, PlotLegends → "Expressions",
 GridLines → {Range[0, 140, 20], Range[0, 3000, 375]},
 FrameTicks → {{Range[0, 3000, 375], None}, {Automatic, None}}]
```

Out[ ]=



10. Parallel hybrid

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 N·m 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	assumed to be 100%

Driving at 90 km/h the traction force is 400 N and the EM shaft torque is 0 N·m

a) Which gear leads to the lowest fuel consumption? Using that gear, what is the engine torque, the engine speed, and what is the engine's BSFC? (2p)

In[ ]:=
```
(*wheel radius in meters*)
vWheelRadius = 0.3;
```

In[ ]:=
```
(*ICE transmission gear ratios*)
gears = 3 * <|"1st" → 3, "2nd" → 2, "3rd" → 1.5, "4th" → 1, "5th" → 0.8|>
```

Out[ ]=
```
<|1st → 9, 2nd → 6, 3rd → 4.5, 4th → 3, 5th → 2.4|>
```

In[ ]:=
```
(*vehicle speed in m/s*)
u = 90 * 1000/(60 * 60);
Quantity[%, "m/s"]
```

Out[ ]= 25 m/s

Recall our transmission model: $\omega_{ICE} = \frac{u_{vehicle}}{r_{wheel}} * k_{gear.tot.}$

In[ ]:=
```
(*wheel speed in rad/s*)
ωWheel = u / vWheelRadius ;
Quantity[%, "rad/s"]
```

Out[ ]= 83.3333 rad/s

In[ ]:=
```
(*engine speed in rad/s*)
ωICE = ωWheel * gears
```

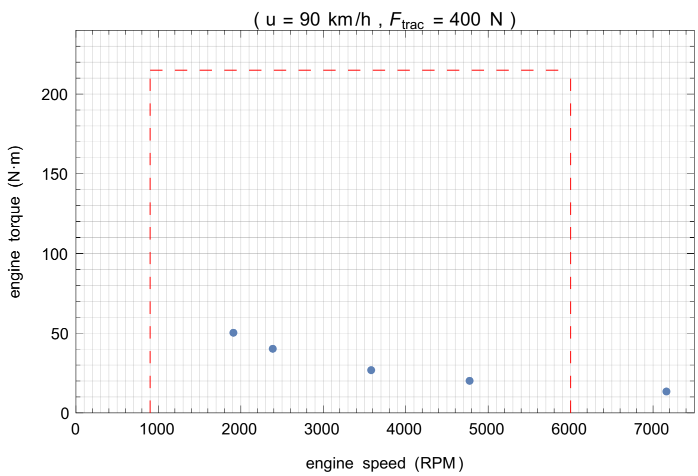
Out[ ]=
```
<|1st → 750., 2nd → 500., 3rd → 375., 4th → 250., 5th → 200.|>
```

In[ ]:=
```
(*engine speed in RPM*)
ωICE = ωWheel * gears * 60/(2 π)
```
Out[ ]= <|1st → 7161.97 , 2nd → 4774.65 , 3rd → 3580.99 , 4th → 2387.32 , 5th → 1909.86 |>

Recall our transmission model: $\tau_{ICE} = F_{trac} * \frac{k_{gear\ .tot\ .}}{r_{wheel}}$

In[ ]:=
```
(*engine torque in N·m*)
τICE = 400 * vWheelRadius/gears
```
Out[ ]= <|1st → 13.3333 , 2nd → 20. , 3rd → 26.6667 , 4th → 40. , 5th → 50. |>

In[ ]:=
```
ListPlot[Transpose[{Values@ωICE, Values@τICE}],
 PlotRange → {{0, 7500}, {0, 240}}, GridLines → {Range[0, 8000, 100], Range[0, 300, 10]},
 PlotLabel → "( u = 90 km/h , Ftrac = 400 N )", Frame → True,
 FrameLabel → {"engine speed (RPM)", "engine torque (N·m)"},
 Epilog → {Red, Dashing[0.02], Line[{{900, 0}, {900, 215}}],
   Line[{{6000, 0}, {6000, 215}}], Line[{{900, 215}, {6000, 215}}]}]
```
Out[ ]=



Lowest fuel consumption in 5th gear: $\tau = 50$ N·m, $\omega = 1910$ RPM, bsfc ≈ 290

In the same driving situation (90 km/h and 400 N traction force), the EM is now charging the battery with 53 kW. The EM torque is then -70 N·m.

b) Which gear leads to the lowest fuel consumption now? Using that gear, what is the engine torque, the engine speed, and what is the engine's BSFC? (3p)

Since the vehicle speed is the same, the engine speeds are also the same as in (a).
The EM will add additional load to the engine. The additional torque can be calculated as if it is an additional wheel torque, using the gear ratio from EM to wheels:

```
In[ ]:= τWheelEM = 70 * 10;
Echo[Quantity[%, "N*m"], "τWheelEM = "];
```

» τWheelEM = 700 m N

Depending on which gear is used the additional EM torque will correspond to different additional torque at the engine shaft. The total engine torque is the torque from the traction force (as already calculated in part (a) of this task), plus the additional EM torque.

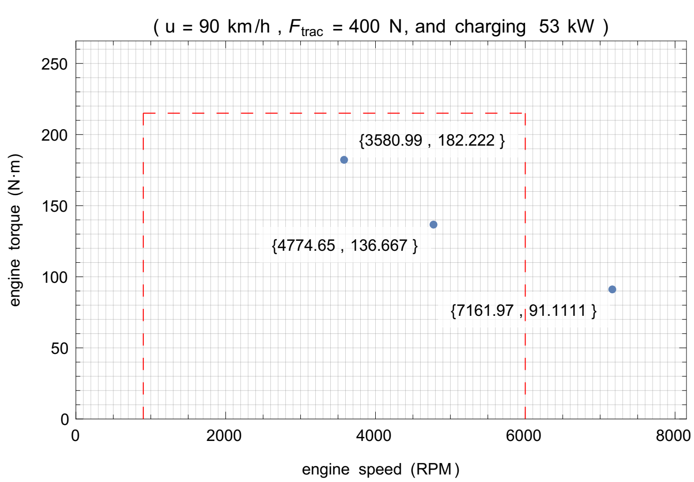
```
In[ ]:= τAdditionalEM = τWheelEM / gears // N
Out[ ]= <|1st → 77.7778, 2nd → 116.667, 3rd → 155.556, 4th → 233.333, 5th → 291.667|>

In[ ]:= τICE
Out[ ]= <|1st → 13.4033, 2nd → 20.105, 3rd → 26.8067, 4th → 40.21, 5th → 50.2625|>

In[ ]:= τICEwithEM = τICE + τAdditionalEM
Out[ ]= <|1st → 91.1111, 2nd → 136.667, 3rd → 182.222, 4th → 273.333, 5th → 341.667|>

In[ ]:= ListPlot[(Labeled[#, #] & /@ Transpose[{Values@ωICE, Values@τICEwithEM}]),
  PlotRange → {{0, 7500}, {0, 240}}, GridLines → {Range[0, 8000, 100], Range[0, 300, 10]},
  PlotLabel → "( u = 90 km/h , F_trac = 400 N, and charging 53 kW )",
  Frame → True, FrameLabel → {"engine speed (RPM)", "engine torque (N·m)"},
  Epilog → {Red, Dashing[0.02], Line[{{900, 0}, {900, 215}}],
    Line[{{6000, 0}, {6000, 215}}], Line[{{900, 215}, {6000, 215}}]}]
```

Out[ ]=



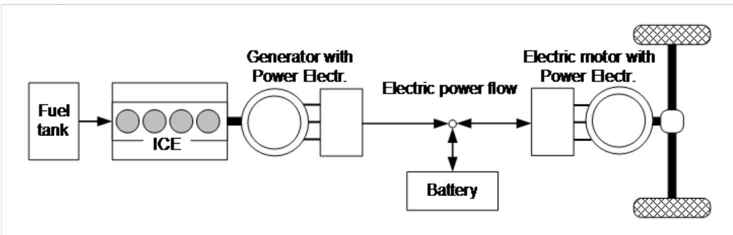
Lowest fuel consumption in 3rd gear: $\tau = 182.2$ N·m, $\omega = 3581$ RPM, bsfc ≈ 290

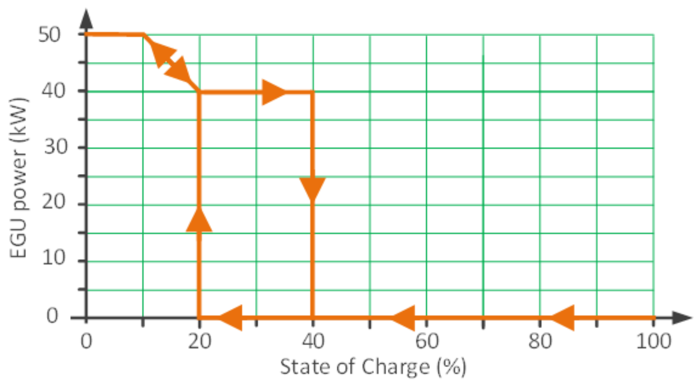
11. Series hybrid control

A series hybrid has the powertrain shown in the figure below and has the following data:

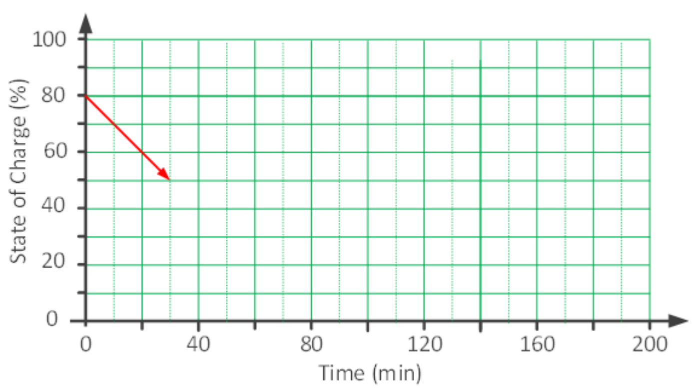
- Maximum traction motor power 150 kW

- Battery capacity 50 kWh
- Max power generated by range extender 50 kW

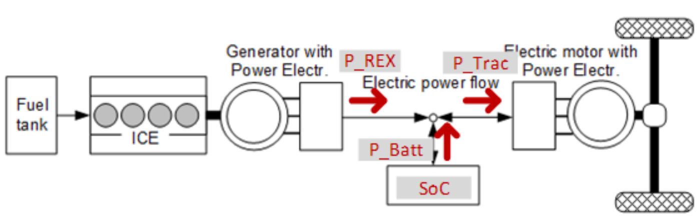




The vehicle starts a trip with 80% SoC and Range Extender Off. The battery SoC follows the red curve in the below diagram for the first 30 minutes of the trip.



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



At the start of the trip the REX is OFF, i.e. $P_{REX} = 0$

$SoC_0 = 80\%$

$SoC_1 = 50\%$

Since the REX is off all power comes from the battery during the first 30 minutes. The battery power equals the change in energy divided by the time of the change: $P_{batt} = \Delta W_{batt} / \Delta T$

```
In[ ]:= Module[{wBattCap = 50, Δt = 0.5, ΔSoC = 0.8 - 0.5, pBatt},
   pBatt = (ΔSoC * wBattCap) / Δt;
   Echo[Quantity[#, "kW"] &@(pBatt), "Pbatt:"]];
```

» P_{batt}: 30. kW

b) Continue the curve showing the battery SoC as a function of time from all the way to 200 minutes in a diagram with SoC versus time. *(For full points your diagram shall be accompanied by calculations of how the SoC changes and motivations explaining why the SoC curve changes behavior over the trip).* (3p)

First, $P_{REX} = 0$ and the SoC curve continues with constant slope for 30 minutes (t1 = 30 minutes). Accord - ing to our controller, we continue at this power with REX off until SoC reaches 20%. This happens at time, t2 = 60 minutes.

At 60 minutes, the REX is turned ON and produces 40 kW.

```
In[ ]:= Module[{pTrac = 30, pREX = 40, pBatt},
   pBatt = pTrac - pREX;
   Echo[Quantity[#, "kW"] &@(pBatt), "(Battery is charging) Pbatt:"]];
```

» (Battery is charging) P_{batt}: - 10 kW

According to our controller, this charging at this rate should continue until SoC increases to 40%.

```
In[ ]:= Module[{wBattCap = 50, Δt, ΔSoC = 0.2 - 0.4, pTrac = 30, pREX = 40, pBatt},
   pBatt = pTrac - pREX;
   Δt = ΔSoC * wBattCap / pBatt;
   Echo[Quantity[#, "hours"] &@(Δt), "Δt charging from 20 to 40%:"]];
```

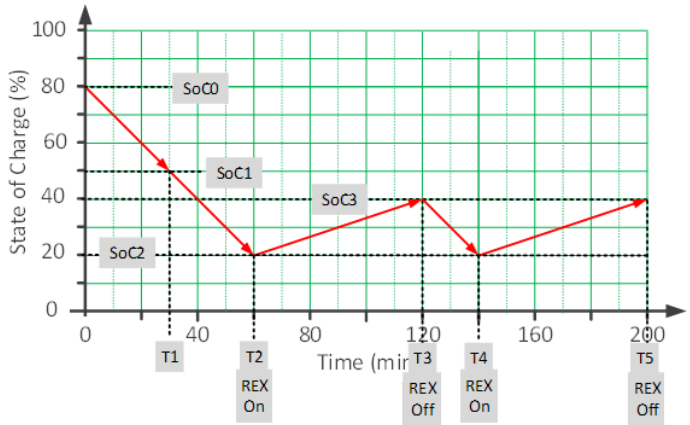
» Δt charging from 20 to 40%: 1. h

Since it takes 1 hour to charge to 40% SoC, t3 = 120 minutes. At 120 minutes the REX is turned OFF, and the battery is again discharged by 30 kW (i.e. same slope as initial part of the trip). Now starting from 40%, it takes only 20 minutes to reach 20% SoC again (t4 = 140 minutes).

```
In[ ]:= Module[{wBattCap = 50, Δt, ΔSoC = 0.4 - 0.2, pTrac = 30, pREX = 0, pBatt},
   pBatt = pTrac - pREX;
   Δt = ΔSoC * wBattCap / pBatt;
   Echo[Quantity[#, "hours"] &@(Δt), "Δt discharging from 40 to 20% SoC:"]];
```

» Δt discharging from 40 to 20% SoC: 0.333333 h

At 140 minutes the REX is turned ON a second time, charging with 40 kW as before with same power demand from the vehicle, so again it takes 1 hour to charge to 40% (t5 = 200 minutes).



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)

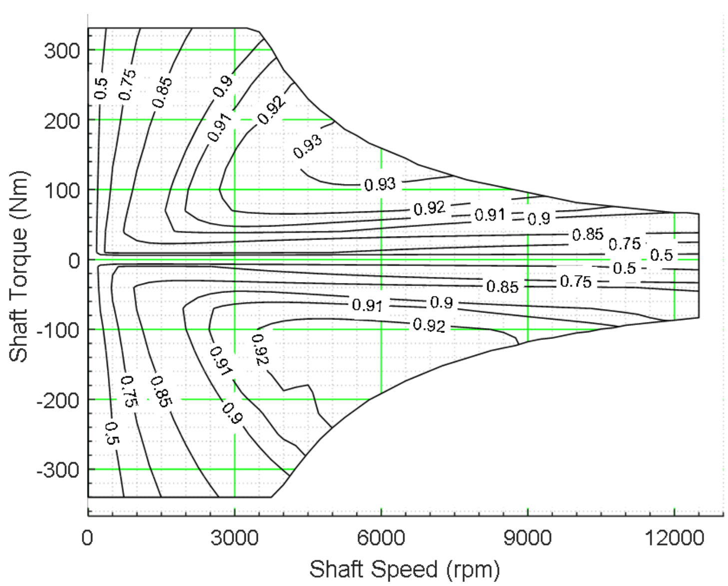
The battery SoC can only reach 5% if the traction power exceeds 50 kW (the max REX power) for an extended period of time. For example, if the vehicle is driven on a steep grade, or at a high speed for a long period of time.

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%

In[▫]:=



```
In[ ]:= (*wheel radius in meters*)
vWheelRadius = 0.3;
Quantity[%, "m"]

Out[ ]= 0.3 m
```

```
In[ ]:= (*vehicle top speed in m/s*)
vTopSpeed = 125. * 1000/(60 * 60);
Quantity[%, "m/s"]

Out[ ]= 34.7222 m/s
```

```
In[ ]:= (*assemble vehicle data for computations*)
vehicle = <|"wheel radius" → vWheelRadius, "top speed" → vTopSpeed|>;
```

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 (0 km/h)? (1p)

Recall our transmission model: $\omega_{EM} = \frac{u_{vehicle}}{r_{wheel}} * k_{gear.tot}$.

To maximize the traction force the highest possible gear ratio should be used, and that is achieved in an arrangement where the EM reaches its maximum speed at the maximum vehicle speed.

```
In[ ]:= ωEMmax = 12500. * (2 π)/60;
Quantity[%, "rad/s"]

Out[ ]= 1309. rad/s
```

```
In[ ]:= kGear = Module[{u = vehicle["top speed"],
    ωEM = ωEMmax, r = vehicle["wheel radius"], kGear, eqn, sol},
   eqn = (u == ωEM/kGear * r);
   sol = kGear /. NSolve[eqn, kGear];
   Echo[First@sol, "kGear:"];]

» kGear: 11.3097
```

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

Recall: $\tau = F * \frac{r_{wheel}}{k_{gear}}$

In[ ]:=
```
tEM = 6000/kGear * vehicle["wheel radius"];
Quantity[%, "N·m"]
```

Out[ ]= 159.155 m N

In[ ]:=
```
Quantity[30. * 1000/(60 * 60), "m/s"]
```

Out[ ]= 8.33333 m/s

Recall our transmission model: $\omega_{EM} = \frac{u_{vehicle}}{r_{wheel}} * k_{gear.tot}$.

In[ ]:=
```
ωEM = ((30. * 1000/(60*60))/vehicle["wheel radius"] * kGear)
Quantity[% * 60/(2 π), "rev/min"]
```

Out[ ]= 314.159

Out[ ]= 3000. rev/min

Then we can read the efficiency of the EM-inverter for the EM operating point (3000 rpm and 159 N m) from the diagram.

In[ ]:=
```
ηEM = 0.92;
pEM = tEM * ωEM;
UnitConvert[Quantity[%, "W"], "kW"]
```

Out[ ]= 50. kW

In[ ]:=
```
powerBattery = pEM/ηEM;
UnitConvert[Quantity[%, "W"], "kW"]
```

Out[ ]= 54.3478 kW

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

In[ ]:=
```
ωEM = ((105. * 1000/(60*60))/vehicle["wheel radius"] * kGear) * 60/(2 π);
Quantity[%, "rev/min"]
```

Out[ ]= 10 500. rev/min

From the diagram, 10500 rpm gives negative 100 N·m of EM torque, and an efficiency near 90.5%.

```
In[ ]:= tEM = -100;
        Quantity[-100, "N·m"]
Out[ ]= -100 m N

In[ ]:= ηEM = 0.905;

In[ ]:= pEM = (ωEM * (2 π)/60) * tEM * ηEM;
        Quantity[%, "W"]
Out[ ]= -99 509.9 W
```

13. Dune buggy EV

A concept car demonstrates a battery electric vehicle design for off-road driving in sandy terrain. The proposed design features a 150 kW electric motor with single speed transmission and claims a range of 250km (as measured on the WLTP cycle). What advantages and does this design have over the IC engine powered "dune buggy" concepts that are often favored in loose sand environments? How would you improve on this design to create a vehicle with more range and aggressive driving capabilities?

14. Quebec City HEV

Quebec City, Canada has an average 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/from work) and also offer a range greater than 500 km under these adverse weather conditions?