EV Battery Cell. Technical data

31 Ah NMC Li-ion cell specifications

- Nominal Capacity = 31 Ah
- Nominal Voltage = 3.7 V
- Voltage range = 3.4 V - 4.2 V
- Nominal energy capacity = 114.7Wh
- Series resistance = 3.6 mΩ

Operating temperatures

- Charge = 0°C / +40°C
- Discharge = -20°C /+ 60°C

Dimensions

- Thickness = 8.4 mm
- Width = 215 mm
- Length = 220 mm
- Weight 1 kg

EV Battery Pack. Technical data

Configuration:

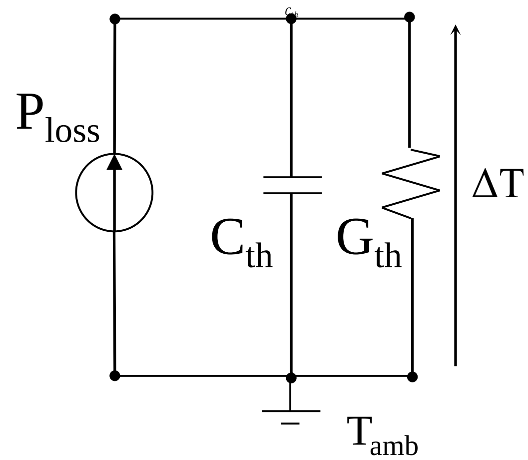
- 100 cells in series, 3 branches in parallel (100S-3P)
- Total number of cells: 300
- DC Round trip efficiency RTE = 94%

First calculations

- Nominal Capacity = 93 Ah
- Nominal Voltage = 370 V
- Nominal energy capacity = 34,4kWh
- Equivalent series resistance = 120 mΩ
- Net weight (only cells) = 300kg

Thermal model of battery pack

- Cell specific heat
  - C_p= 800 J/kg K
- Battery thermal capacity
  - C_{th} = 800 J/kg K x 300kg = 240kJ/K



$$\Delta T = \frac{1}{C_{th}s + R_{th}} P_{loss}$$

Two cooling methods are possible:

- air cooling and liquid cooling (more efficient)
- The same heat exchange area is chosen for both cooling methods = 0.5m^2
- Air convection coefficient $K_{th\text{-}air}$ = 200 W/m^2 K
- Glycol convection coefficient $K_{th\text{-}glyc}$ = 2000 W/m^2 K
- Air convection $G_{th\text{-}a}$ = $K_{th\text{-}air}$ x 0.5m^2 = 100 W/K
- Glycol convection $G_{th\text{-}g}$ = $K_{th\text{-}glyc}$ x 0.5m^2 = 1000 W/K

Vehicle data

- Average Kerb Weight = 1500 kg
- DC link battery voltage = 370 V
- Tank-to-Wheel efficiency = 80%
- Regenerative braking percentage = 50%
- Rolling resistance coefficient fv, tire on road = 0.02
- Shape coefficient cv = 0.29
- Vehicle frontal area = 2.38 m^2
- Wheel radius = 0.35m

- The EV is equipped with a 60kW electric motor

- The kerb weight refers to the car loaded with all the fluids for its operation plus the weight of an average driver.
- The Tank-to-Wheel (T2W) efficiency takes into account the mechanical transmission, the electric motor and the inverters.
- Mechanical transmission has only one gear.
  - Transmission ratio kt = N motor/N wheel = 5

Variable speed characteristics of 60kW electric motor

Base speed = 1500 rpm

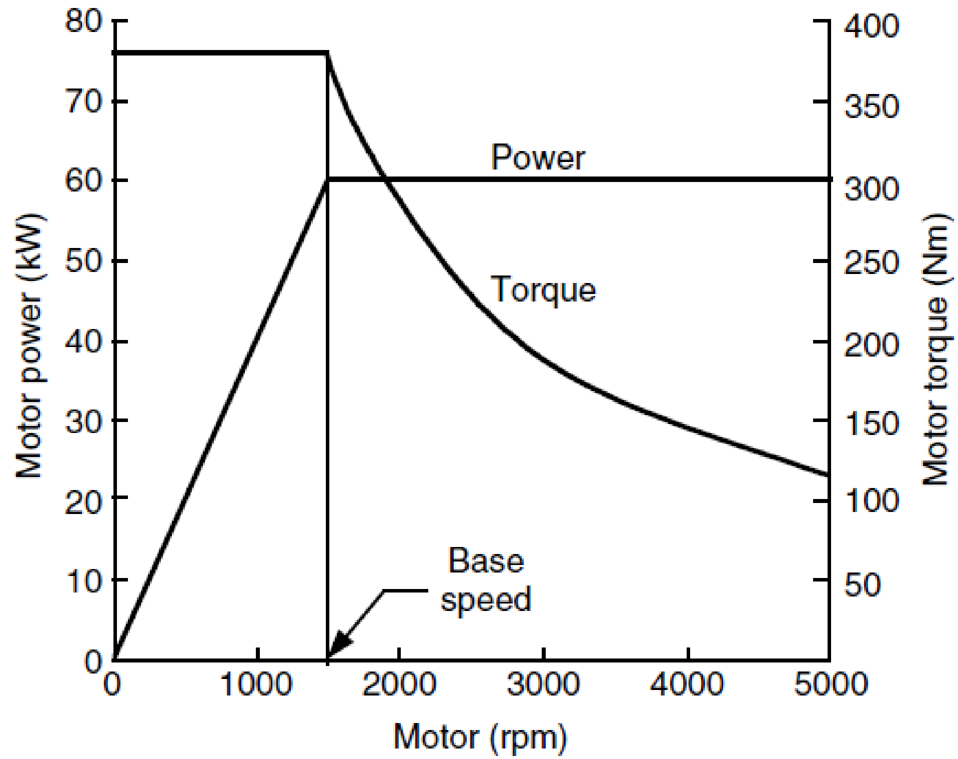
Max speed = 6000 rpm

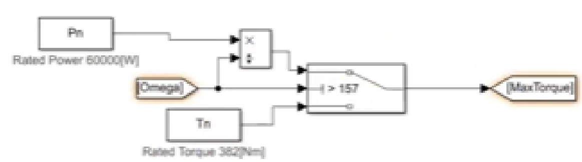
X = max/base speed = 4

Base angular speed = 157 rad/s

Torque @ base speed = 382 Nm

Power = 382Nm x 157 rad/s = 60kW





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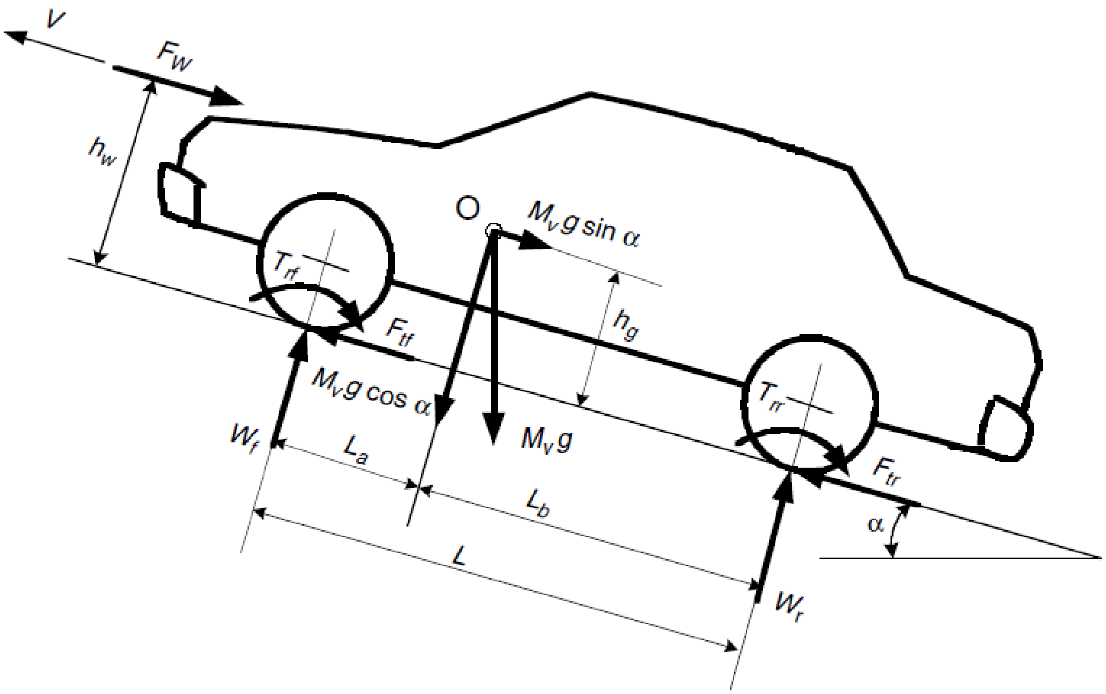
Calculation of electric power Pe



Forces acting on vehicle
In this exercise the grading resistance is neglected, assuming **α=0**

An additional constant load of **800W** has to be added to account for the power of the auxiliaries, such as heater or air conditioning

$$R_{rolling} = f_v \cdot m \cdot g$$
$$R_{aerodynamic} = \frac{1}{2}\rho_{air} \cdot A_{vehicle} \cdot v^2 \cdot c_v$$
$$P_r = F_T \cdot v = \left(R_{rolling} + R_{aerodynamic}\right) \cdot v$$
$$P_m = P_r + m \cdot a \cdot v$$
$$P_e = P_m / \eta_{T2W}$$

Mass m = 1500 kg
Tank-to-Wheel efficiency η_{T2W} = 80%
Max Regenerative braking current = C2
Rolling resistance coefficient f_v = 0.02 pu
Shape coefficient c_v = 0.29 pu
Vehicle frontal area $A_{vehicle}$ = 2.38 m^2
Gravity acceleration g=9.81m/s^2
Air density ρ_{air} = 1.2 kg/m^3

Simulations required

Slow charge

A 7.2kW single phase rectifier (OBC = on board battery charger) charge the battery at approximately C4, with a current equal to one quarter of capacity, up to a SoC = 90%, starting from SoC = 20%

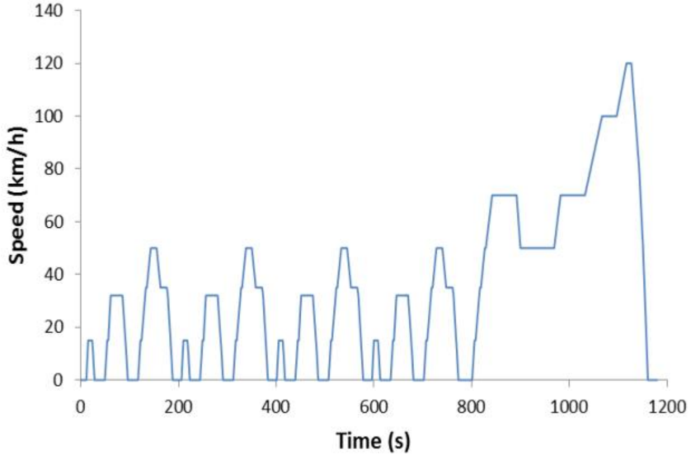
Fast charge

A 50kW three phase rectifier (converter located in the external charger, EVSE = EV Supply Equipment) charge the battery at approximately 1.5C for 20 minutes, starting from SoC = 20%

Driving session, two NEDC cycles

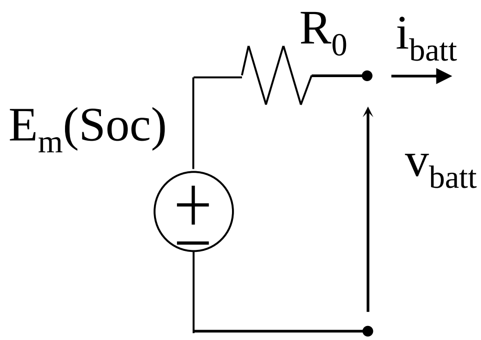
Calculate and draw the curves vs time of:

- Energy consumption
- Battery temperature
- SoC



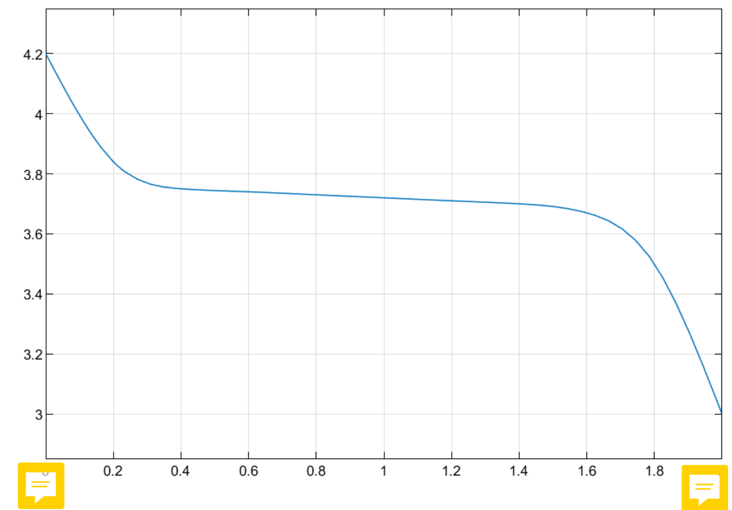
Slow charge

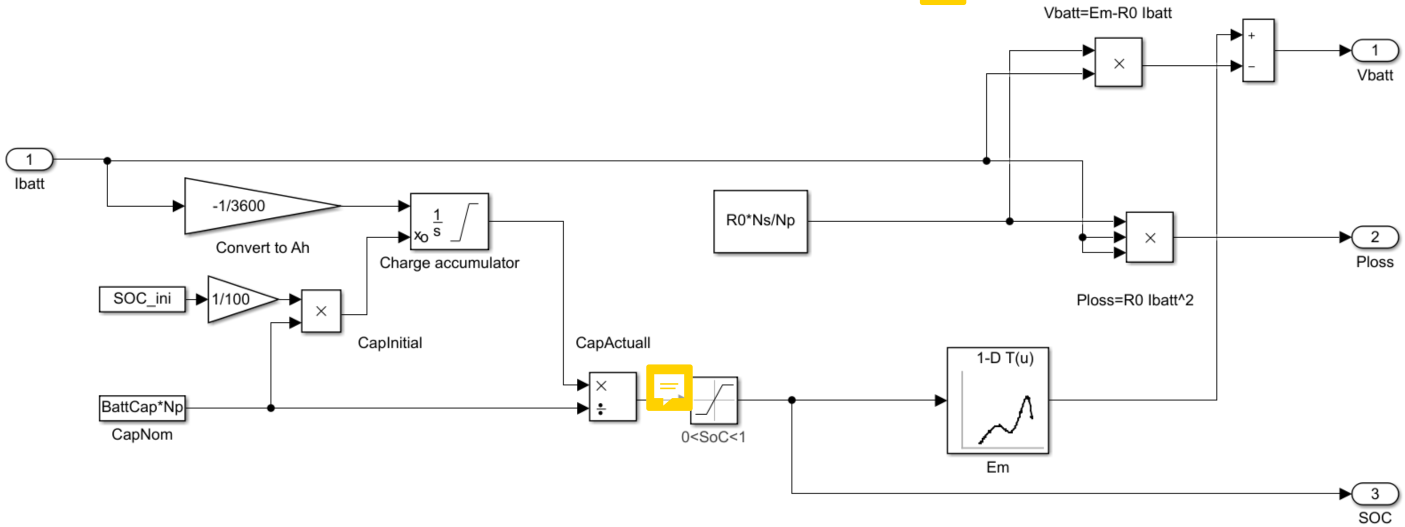
- Simple Battery model
  - No dependecy on the temperature



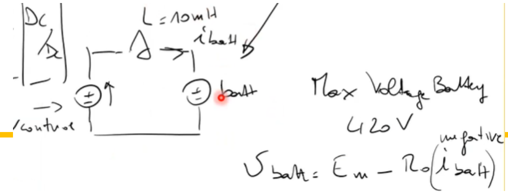
E_m(SoC): single module

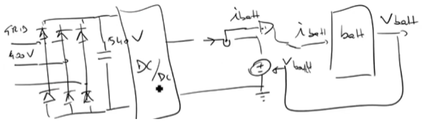
R_0= 3.6 mΩ



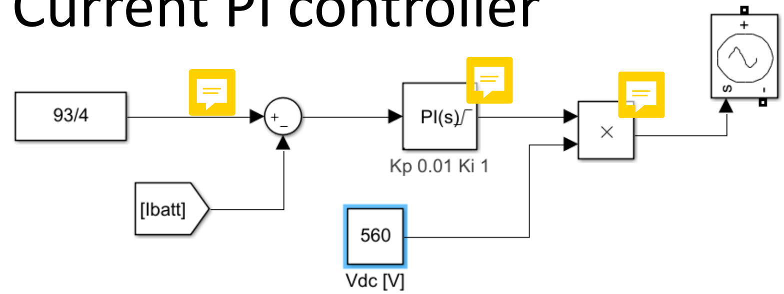


Slow charge



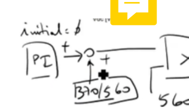


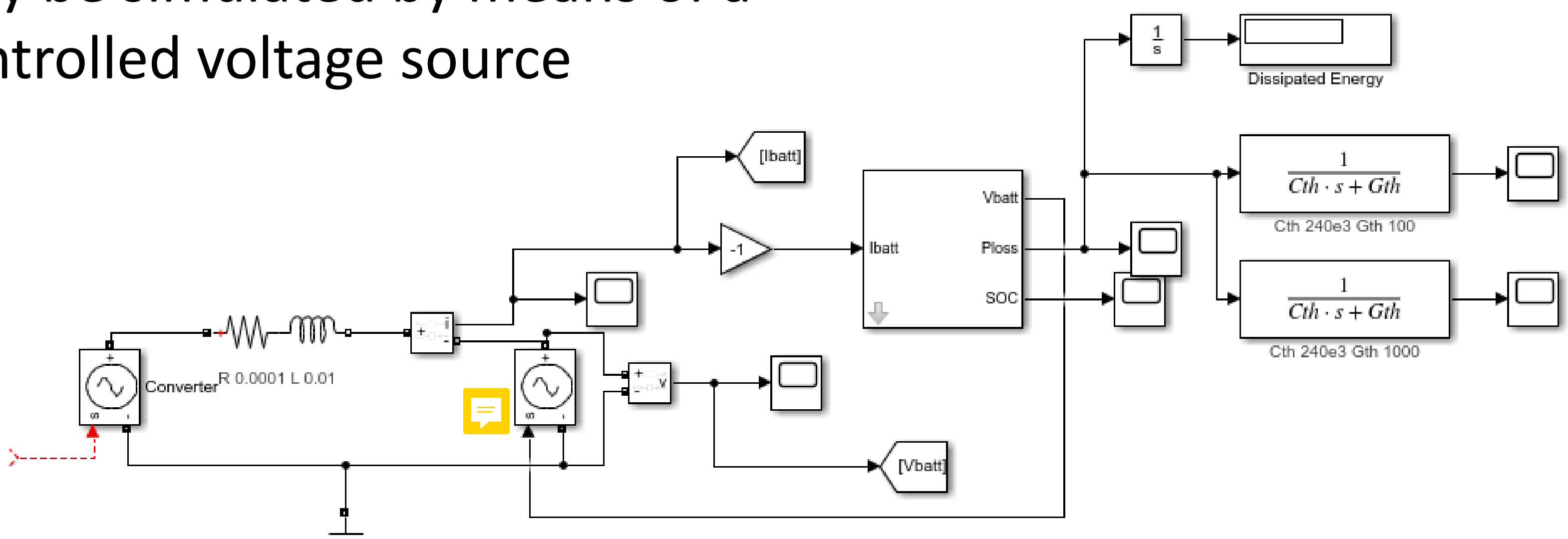
Current PI controller



Between the converter and the battery an de-coupling inductor is required (i.e. 10mH)

The converter and the battery may be simulated by means of a controlled voltage source





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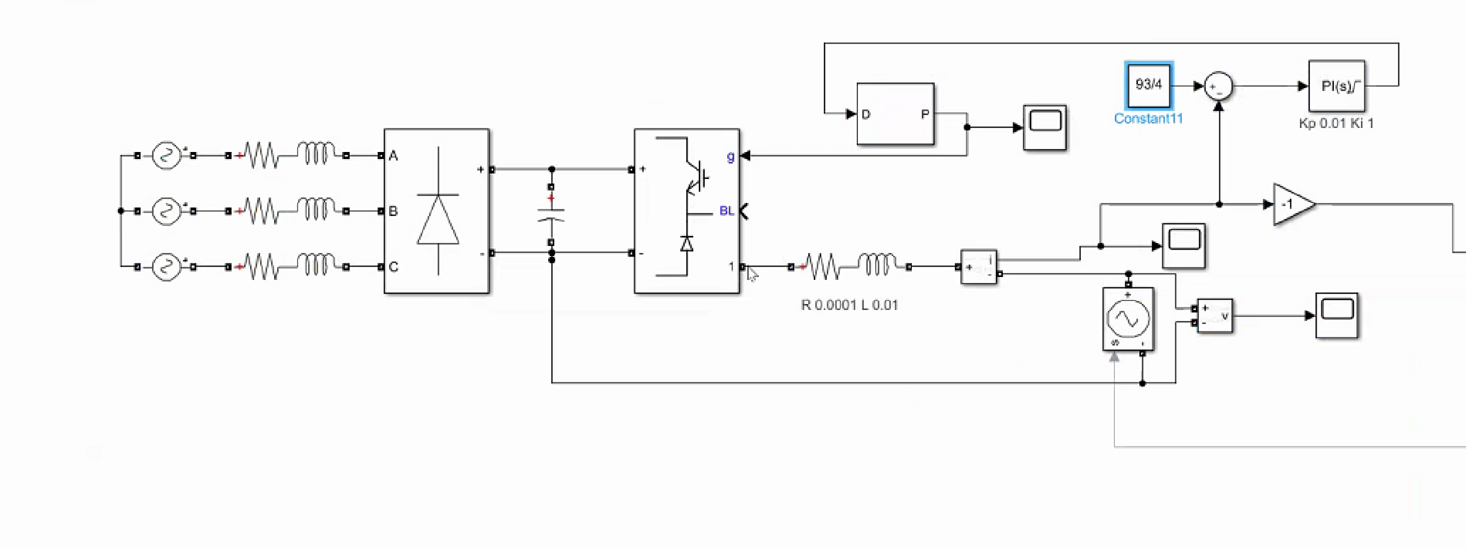
Fast charge

- Similar to Slow charge



Driving cycle

The speed controller requires a torque. In order to find the battery current, an energy balance may be applied, taking into account the Tank-to-Wheel (η_{T2W}) efficiency = 80%.
η_{T2W} is the product of the efficiency of the mechanical load η_{mech} and of the electrical devices (machine and converter) η_{el} . Suppose η_{el}=97%. Therefore, η_{mech} = 82.5%
The battery power Pbatt is Vbatt x Ibatt while the mechanical power at the motor shaft Pe is Te x Ω_m. During motor operation, the Pbatt=P_{aux}+Pe/ η_{el} . During braking operation, the Pbatt=Pe x η_{el}-P_{aux}

Calculate and draw the curves vs time of:

- Energy consumption
- Battery temperature
- SoC

Driving cycle: Open loop approach

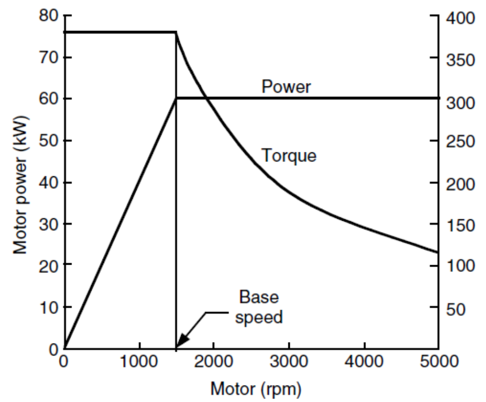
NEDC cycle gives speed *v* and acceleration *a*

- $R_{rolling} = f_v \cdot m \cdot g$
- $R_{aerodynamic} = \frac{1}{2}\rho_{air} \cdot A_{vehicle} \cdot v^2 \cdot c_v$
- $P_r = F_T \cdot v = \left(R_{rolling} + R_{aerodynamic}\right) \cdot v$
- $P_m = P_r + m \cdot a \cdot v$
- If Pm>0 then $P_e = P_m/\eta_{T2W}$ else $P_e = P_m \cdot \eta_{T2W}$
- Pbatt=Pe+800W
- Ibatt=Pbatt/Vbatt
- The battery model returns the new value of Vbatt, SoC and Power Losses in the battery

Driving cycle: Closed-loop approach

NEDC cycle gives speed reference *vref* (*v* is the actual speed)

- A linear speed controller (PI) asks for an electromagnetic torque reference
- It is limited to the maximum torque given by the operating regions (The curve of negative torque is mirrored from the positive one)
- Ω_m =*v*/radius x TransmissionRatio=*v x* k_{tr}
- Te x Ω_m is the electromagnetic power Pem
- If Pem>0 then $P_e = P_{em}/\eta_{el}$ else $P_e = P_{em} \cdot \eta_{el}$
- Pbatt=Pe+800W
- Ibatt=Pbatt/Vbatt
- The battery model returns the new value of Vbatt, SoC and Power Losses in the battery



Driving cycle: Closed-loop approach

Towards the mechanical load:

- $R_{rolling} = f_v \cdot m \cdot g$
- $R_{aerodynamic} = \frac{1}{2}\rho_{air} \cdot A_{vehicle} \cdot v^2 \cdot c_v$
- $F_T = R_{rolling} + R_{aerodynamic}$

The electromagnetic force Fe, taking into account the mech. efficiency is:

- If Te>0 then $F_e = k_{tr}T_e \cdot \eta_{mech}$ else $F_e = k_{tr}T_e/\eta_{mech}$
- $a = \frac{1}{m}(F_e - F_T)$
- $v = \int a \cdot dt$

I used, for the speed controller, Kp=1 and Ki=100, saturation between -1 and 1, output gain=328Nm

Some results

- Starting from 100% of SoC. Total distance 22km