# Simplified longitudinal model

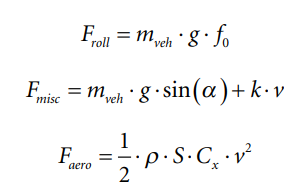
The references for the longitudinal vehicle model are: [1 - 2020 Anselma - Enhancing Energy Saving Opportunities through Rightsizing of a Battery Electric Vehicle Powertrain for Optimal Cooperative Driving] and [2 - B. Onori - HEV – EMS]. Both in References>Modelling.

The backward approach is used for the modeling of the system.

The output torque of the vehicle should compensate the road resistive loads and the acceleration demand. It is given by:

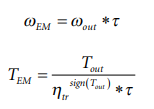


With:

”

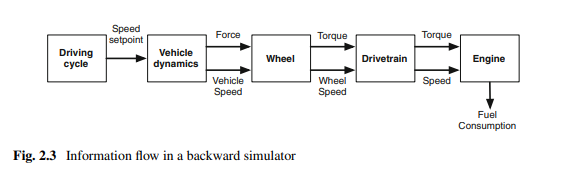
“F\_roll, F\_misc, and F\_aero are resistive load terms provided by the rolling resistance, some miscellaneous terms (e.g., transmission losses, side forces, road slope) and aerodynamic drag, respectively. m\_veh and r\_wheel represent vehicle mass and wheel effective radius, respectively. g, α, and ρ stand for the gravity’s acceleration, the road slope, and the air density, respectively; f\_0, k, S, and C\_x are vehicle parameters corresponding to the rolling friction coefficient, a miscellaneous loss coefficient, the frontal area, and the drag coefficient, respectively.”[1]

The transmission equations are:



“ωEM and ωout represent values of angular speed for the EM and wheels, respectively; TEM, the EM torque, can assume positive or negative values depending on propelling or braking conditions; η\_tr is the efficiency of the transmission system that includes loss of the rotating parts and gear meshing: its value can be assumed constant for preliminary calculations. The sign of the desired transmission output torque as exponent allows accounting for both driving and braking scenarios [36].” [1]

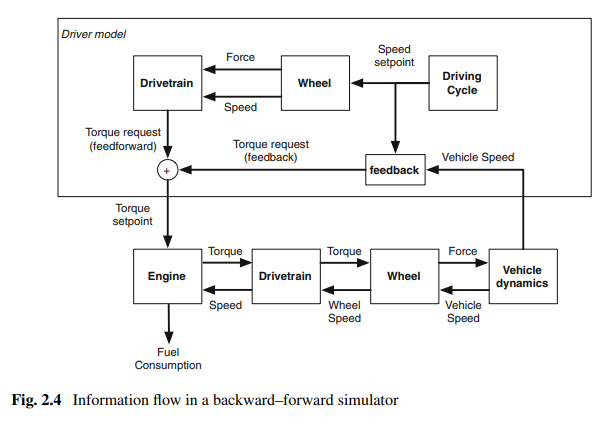
The backward modelling approach is illustrated in the following scheme [2]:



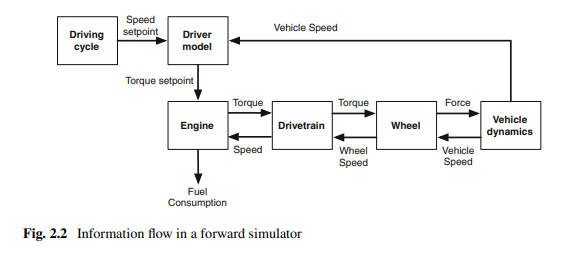
In the backward approach the driving cycle or reference speed is given as an input of the system (no need for a driver model to compare the reference speed with the actual vehicle speed), and the engine (or EM in our case) torque and fuel consumption (battery consumption for us) are the outputs. The vehicle dynamics and powertrain loads are calculated from the reference speed profile, and the torque that should be provided by the EM (or engine) should be sufficient to compensate the road resistive forces, the vehicle and powertrain loads, and supply the desired vehicle acceleration. The traction force can be isolated and obtained in the backward approach [2]:



“Both the forward and backward simulation approaches have their relative strengths and weaknesses. Fuel economy simulations are typically conducted over predetermined driving cycles, and therefore using a backward simulator ensures that each different simulation exactly follows this profile, which guarantees consistency of simulation results. By contrast, a forward simulator may not exactly follow the trace, as it introduces a small error between the actual and the desired signal. Proper tuning of the driver block can reduce the differences, whereas the backward version keeps the error at zero without any effort. On the other hand, a backward simulation assumes that the vehicle and powertrain are capable of following the speed trace, and does not account for limitations of the powertrain actuators in computing the vehicle speed, which is predetermined. This poses the problem of evaluating demanding cycles which may require more power than the powertrain can provide. A forward simulation does not have this issue, because the speed is computed from the torque/force output, which can be saturated according to the powertrain limitations. For this reason, forward simulation can also be used for acceleration tests and in general for testing the behavior of the system at saturation. In addition, forward simulators are implemented according to physical causality and, if their level of detail is appropriate, can be used for development of online control strategies, while a backward simulator is suited for preliminary screening of energy management strategies. It is possible to combine the advantages of both modeling approaches, i.e., the accurate reproduction of a cycle by a backward simulation and the ability to capture powertrain limitations of a forward simulator. A solution, represented in Fig. 2.4, consists in using a forward simulator in which the driver model (speed controller) uses a backward vehicle model to compute the torque setpoints to be applied: in this way, the resulting speed profile will match exactly the reference cycle, if this does not saturate the powertrain capacity, but will be appropriately saturated when needed since it goes through a forward powertrain model. A feedback term should also be added, in order to recover speed deviation due to powertrain saturation (or to possible mismatches between the backward and forward models).”[2]

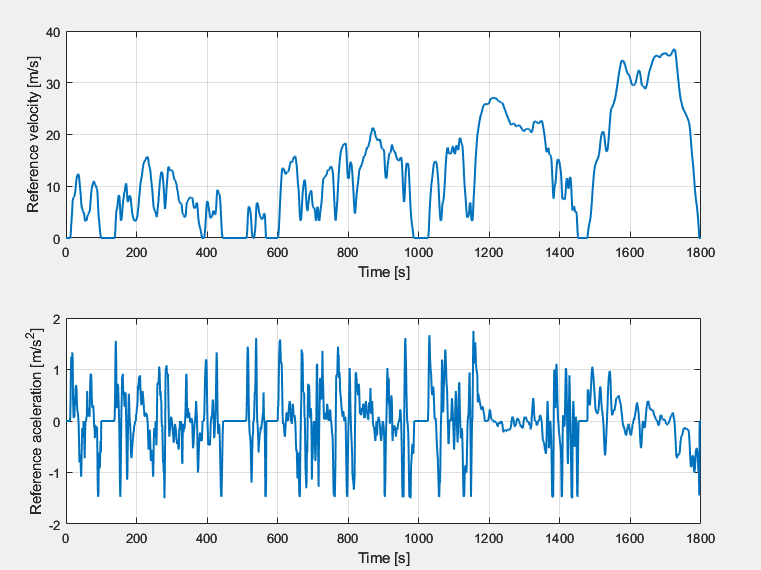


Foreward approach:



## Reference speed to input torque equations.

Given the WLTP 3 driving cycle shown below, the speed and accelerations profiles are turned into a torque input for the simplified longitudinal dynamics model of the vehicle.

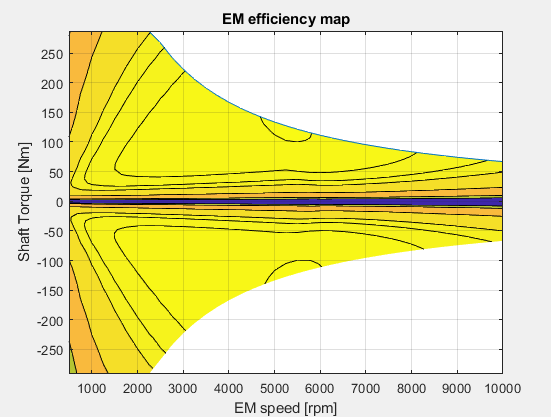


# Simplified eMotor model [1].

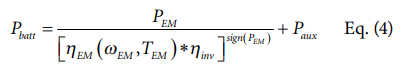
Electric Motor and Generator:

- maximum torque: 300 Nm (constant up to 3000 rpm)

- maximum speed: 90000 rpm



The EM is modeled by the empirical loss map -> efficiency map of the EM based on torque and speed [37,38]. The battery power can be evaluated by:



“P\_EM represents the EM output power and demonstrates consistent sign with the EM torque; η\_inv is the efficiency of the inverter (assumed having a constant value). Retaining the sign of P\_EM as exponent in the denominator allows capturing both depleting and charging battery conditions within this formula.” [1]

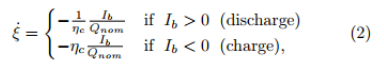
P\_aux is approximated to 0.

# Simplified battery model

The equation of the SOC is defined by:

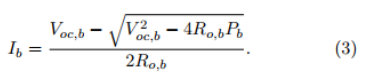


Being the ratio between the charge and discharge current. By differentiating both sides, it is possible to obtain the \dot\_SOC as a function of the currents:

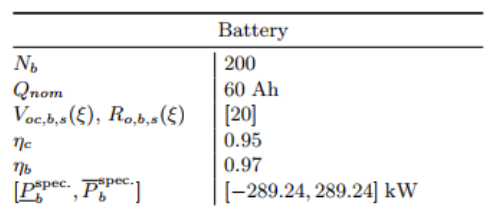


Where \eta\_c is the coulombic efficiency.

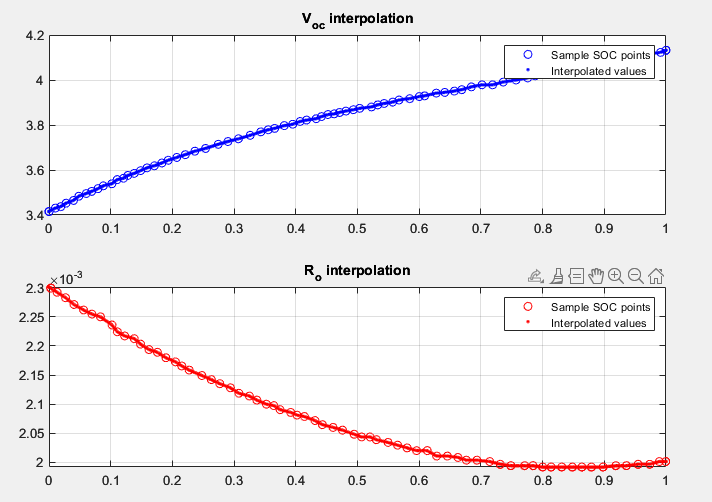
The battery is modeled as an ideal voltage source V\_{oc,b} with series of input resistance R\_{o,b}, so it is possible to solve for the current:



The parameters of the battery are:



The data of voltage and resistance as functions of the SOC are obtained experimentally, and are interpolated in matlab to obtain a function. The values are used in the Simulink simplified model as 1D lookup tables.



Value showed are for 1 cell.

# Vehicle Parameters

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Symbol | Value | Unit |
| Vehicle Mass | M\_veh | 1400 | kg |
| Front axle - CoG | a | 1 | m |
| Rear axle - CoG | b | 1.3 | m |
| Height CoG | h | 0.3 | m |
| Static rolling coefficient | f\_0 | 4.5 | N/kN |
| Wheel radius | r\_w | 0.3 | m |
| Drag coefficient | C\_d | 0.33 | - |
| Frontal area | A\_f | 2.15 | m2 |
| Gear ratio | tau\_gb | 9.6 | - |
| Gearbox efficiency | eta\_gb | 0.97 | - |

# Model states and inputs.

Model inputs:

States of the system:

Control variable:

Use interpreted matlab function in Simulink.

# MPC states

States are:

u\_c is the control input = force provided by the powertrain to follow the reference.

REFERENCES

[1] - 2020 Anselma - Enhancing Energy Saving Opportunities through Rightsizing of a Battery Electric Vehicle Powertrain for Optimal Cooperative Driving

[2] - Hybrid Electric Vehicles Energy Management Strategies – Onori

[36] - Hofman, T. and Dai, C., “Energy Efficiency Analysis and Comparison of Transmission Technologies for an Electric Vehicle,” in IEEE Vehicle Power and Propulsion Conference, Lille, France, 2010, pp. 1-6.