PLECS

DEMO MODEL

Two-Axle Vehicle with Driving Profile

Last updated in PLECS 4.3.1

1 Overview

This demonstration shows a two-axle electric vehicle model with front-wheel drive and highlights the PLECS mechanical domain. The vehicle's driving cycle as well as the tire models have multiple configurations implemented. Traction forces and vehicle weight distribution are also taken into consideration in order to calculate the corresponding torques.

Note

This model contains model initialization commands that are accessible from:
PLECS Standalone: the menu **Simulation > Simulation Parameters... > Initializations**
PLECS Blockset: right click in the **Simulink model window > Model Properties > Callbacks > InitFcn***

2 Model

2.1 System model

The electric motor is connected to the front-wheel axle of the two-axle vehicle model. An ideal Torque Source is used to apply the motor torque on the rotor, modeled here as a rotating body of fixed inertia. The rotor shaft is then connected to the wheel axle through a Gearbox component. The shaft stiffness and damping are modeled using the Torsion Spring and a Rotational Damper components, respectively.

The total traction force generated by both the front and rear wheels is then applied to the vehicle, represented here as a lumped mass. Rotational Friction blocks are used to model the front and rear wheel brakes. The vehicle model converts the applied torque on the wheel axle into a traction force applied on the vehicle using a slip-based wheel model. In addition, the vehicle is connected to a road load through the translational mechanical terminal.

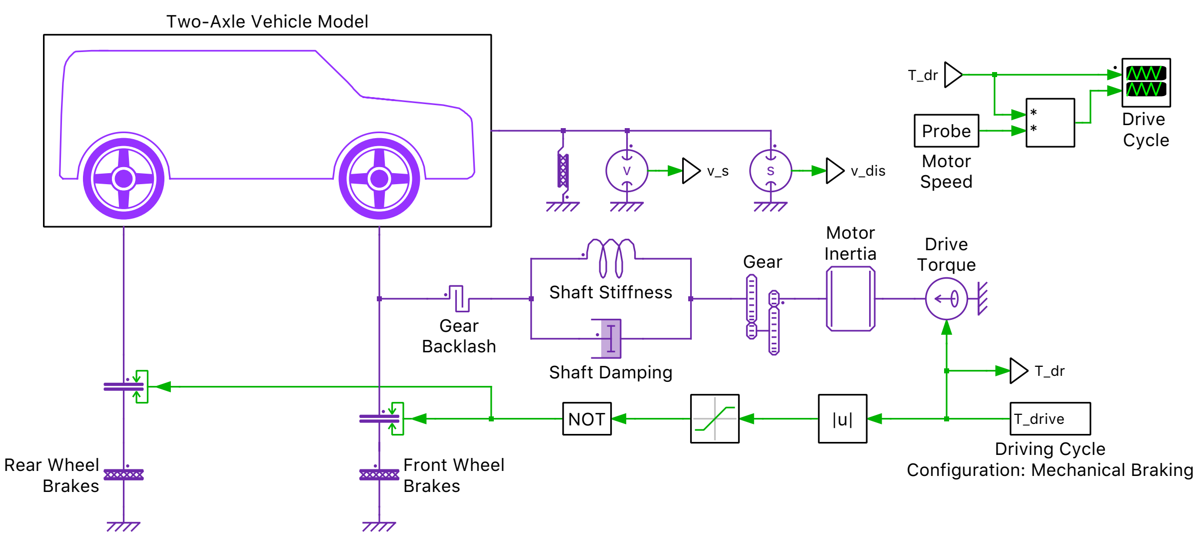

Fig. 1: Two-axle vehicle with driving profile model

2.2 Vehicle model

The weight on the front and rear axle is distributed according to the location of the center of gravity. In this example, the center of gravity is assumed to be closer to the front wheel axle to model a front-engine vehicle. The wheel model converts the torque applied on the wheel axle into a traction force. The total traction force generated by both the front and rear wheels is then applied to the vehicle represented here as a lumped mass. The vehicle model also incorporates the effect of acceleration/deceleration on the weight distribution of the vehicle. The 'Pitch Change Delay' is used to model the stiffness of the suspension system of the vehicle.

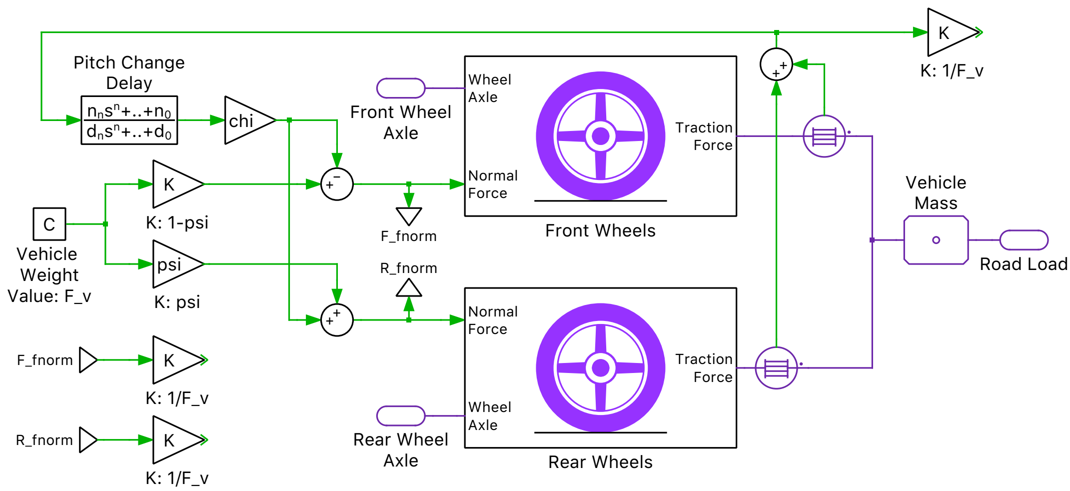

Fig. 2: Two-axle vehicle model

2.3 Wheel model

The torque applied to the wheel axle acts on a wheel, which is modeled in a lumped fashion as a Rotational Inertia block. The rotational speed of the wheel as well as the translational speed of the vehicle (V_s) are both measured. The rotational speed of the wheel is scaled by the radius of the wheel to determine the translational speed of the tire (V_w) near the point of contact with the road. The normal force acting on the wheel axle and the measured speeds (V_w and V_s) are used to calculate the traction force (F_t) applied on the vehicle by the wheels. The applied traction force will then move the total vehicular system.

There are two implementations for the calculation of the tire slip. The 'Basic Tire Model' ignores the transient behavior of the tires while the 'Restricted Fully Nonlinear Model' incorporates the transient behavior. For both implementations, the calculated slip is then translated into a traction force using Pacejka's Magic Formula from [1]:

$$F_{\mathrm{Traction}} = D_{\mathrm{x}} \cdot \sin(C_{\mathrm{x}} \cdot \arctan(B_{\mathrm{x}} \cdot \lambda)),$$

where λ is the tire slip and B_x, C_x, and D_x are Magic Formula coefficients that are determined through experimental characterization of the vehicular system.

3 Simulation

3.1 Driving profile

Fig. 4 below shows the torque applied by the electric motor on the vehicular system over the length of the simulation. A ramped accelerating torque demand is applied on the motor for the first $100\,\mathrm{s}$. At $t = 100\,\mathrm{s}$, the accelerator is slammed down leading to a step change in the torque applied by the electric machine. At $t = 200\,\mathrm{s}$, the driver uses the mechanical brakes to slow the vehicle down, which leads to zero torque being applied by the motor. At $t = 300\,\mathrm{s}$, a negative torque is applied by the motor to reverse the vehicle. This torque is maintained over the next $150\,\mathrm{s}$ when the mechanical brakes are employed again to bring the vehicle to a standstill. Additionally, the power required by the motor is also plotted. As can be seen, the electric machine is only operated in motoring mode in this drive cycle.

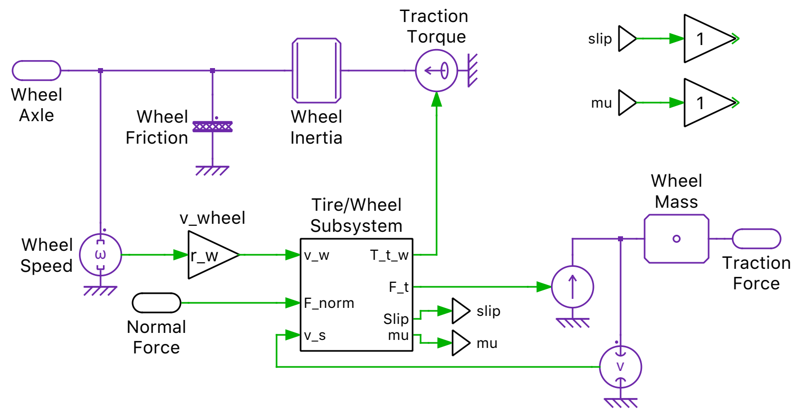

Fig. 3: Wheel model

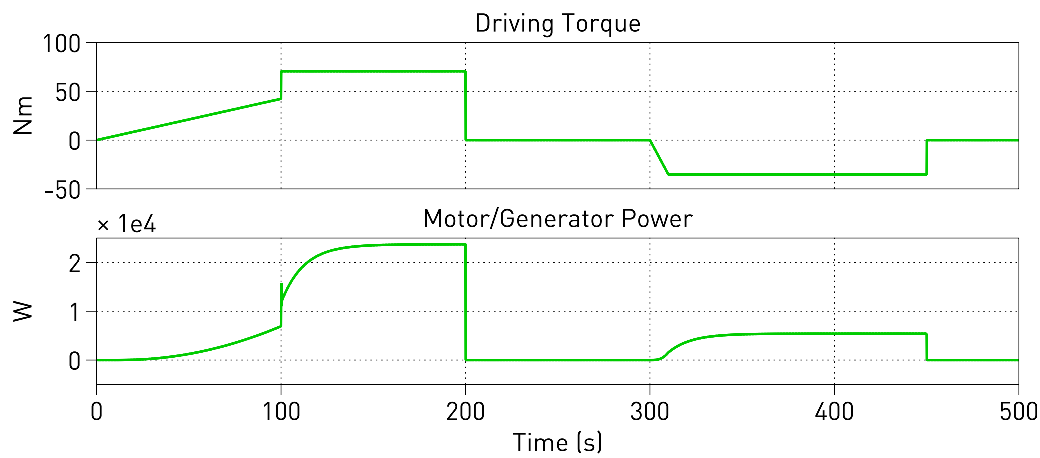

Fig. 4: Mechanical drivecycle

3.2 Velocity

The vehicle is initially at rest. The vehicle accelerates slowly from rest to $36\,\mathrm{km/h}$ over the first $100\,\mathrm{s}$. At $t = 100\,\mathrm{s}$, a step change in torque causes a faster acceleration of the vehicle. The vehicle continues to accelerate until it reaches its final steady-state speed of $74\,\mathrm{km/h}$ at around $t = 150\,\mathrm{s}$. This steady-state speed is maintained until $t = 200\,\mathrm{s}$ and then the brakes are applied, bringing the vehicle to a standstill in $4.7\,\mathrm{s}$. At $t = 300\,\mathrm{s}$, the vehicle is reversed, reaching a final velocity of $-34.9\,\mathrm{m/s}$ at $t = 380\,\mathrm{s}$. This speed is maintained until $t = 450\,\mathrm{s}$ when the brakes are applied to bring the vehicle to standstill in $3.2\,\mathrm{s}$.

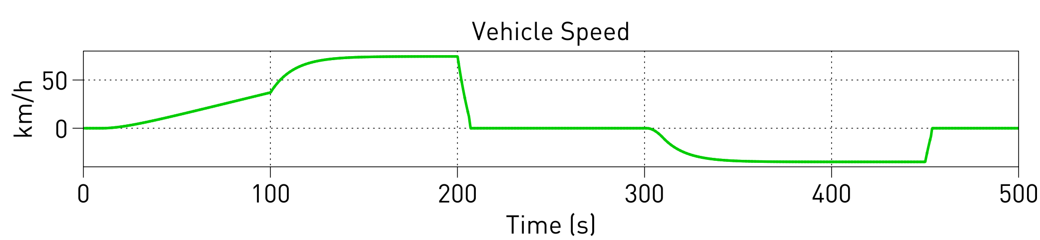

Fig. 5: Vehicle speed

3.3 Weight distribution and accelerating traction force

Fig. 6 below shows the effect of the simulated drive cycle on the weight distribution of this vehicle. The accelerating force applied on the vehicle is shown in an additional plot. As can be seen, the ramped increase in forward acceleration over the first 100 s causes the weight of the vehicle to be slowly shifted to the rear of the vehicle. A step change in driving torque contributes to a sudden shift in the weight distribution of the vehicle to the rear. As the vehicle reaches steady-state speed, a constant weight distribution is maintained. As the vehicle is brought to a quick standstill, the weight is shifted to the front of the vehicle, as can be seen by the green spike at $t = 200\,\mathrm{s}$. As the vehicle is reversed, the weight of the vehicle is shifted towards the front of the vehicle due to acceleration in the negative direction. As the reversing vehicle is brought to a stop, the weight of the vehicle is shifted to the back of the vehicle, as can be seen by the red spike at $t = 450\,\mathrm{s}$. The waveform between $t = 205\,\mathrm{s}$ and $300\,\mathrm{s}$, and $t = 450\,\mathrm{s}$ and $500\,\mathrm{s}$ shows the weight distribution of the vehicle at standstill.

The Traction Force plot shows the accelerating/decelerating force acting on the vehicle over the entire drive cycle. It can be seen that as the vehicle reaches steady-state speed, between $t = 150\,\mathrm{s}$ and $200\,\mathrm{s}$, the vehicle accelerating traction force is zero. During this period, the torque generated by the electric motor is used to overcome the force due to the road load.

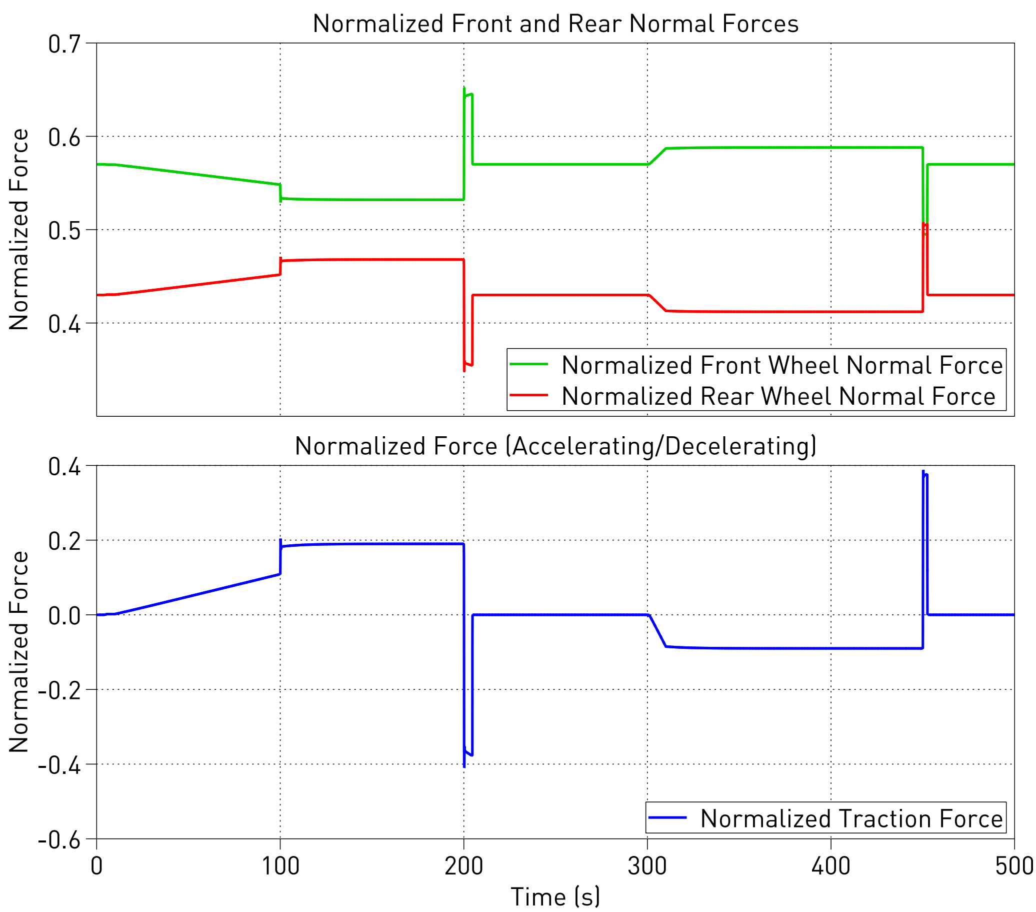

Fig. 6: Mechanical force

3.4 Regenerative braking

An alternative to slowing down the vehicle with mechanical brakes is using the the electric machine as a generator to recapture the kinetic energy. In Fig. 7 below, the negative torque between $t = 200\,\mathrm{s}$ and $205\,\mathrm{s}$ is used to slow down the vehicle, leading to the machine being operated in generator mode, allowing the kinetic energy to be recaptured. Similarly, the positive torque applied between $t = 450\,\mathrm{s}$ and $453\,\mathrm{s}$ is used to slow down the reversing vehicle, allowing the kinetic energy to be recaptured.

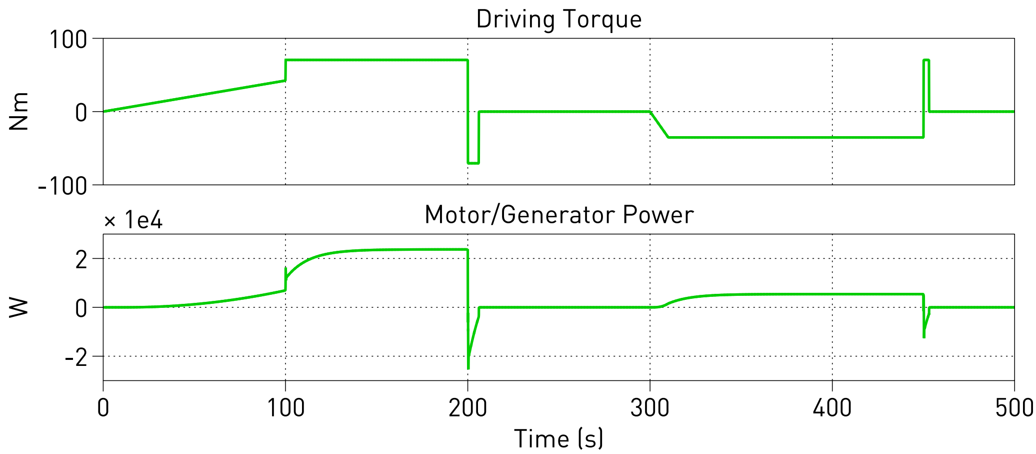

Fig. 7: Regenerative drivecycle

3.5 Restricted non-linear model vs basic model

The simulations may also be repeated using the 'Restricted Fully Nonlinear Model'. This implementation models the transient behavior of the tire/wheel, which results in a wind-up oscillation due to a step change in torque applied to the wheel. Fig. 8 below shows the accelerating/decelerating force applied on the vehicle due to instantaneous mechanical braking of the vehicle. These results correlate with the observations in Chapter 8 of the textbook [1].

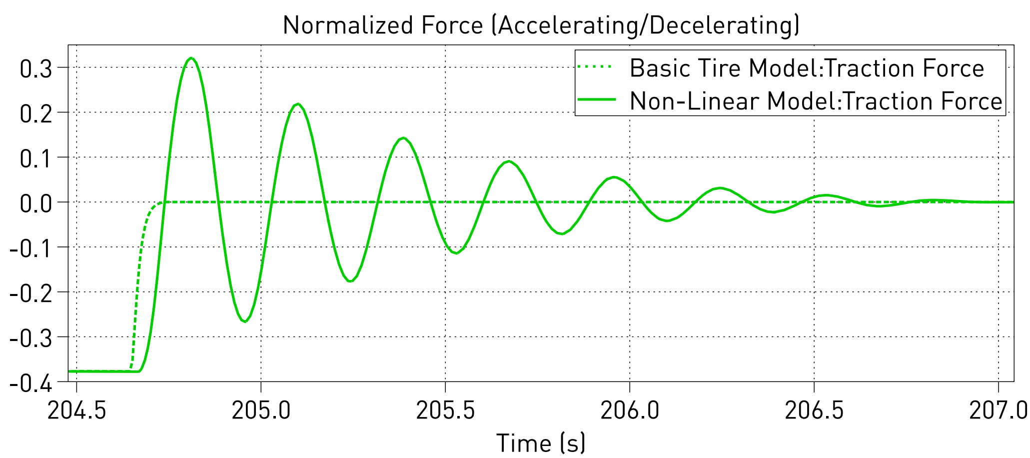

Fig. 8: Wheel implementation comparison

4 Conclusion

This model highlights a two-axle electric vehicle model with a front-wheel drive. PLECS mechanical domain components are used to create a non-linear mechanical load, allowing users to analyze the electrical drive system in more detail. Further enhancements of this model could involve providing a selection of various tire dimensions as well as road conditions. For more models highlighting the mechanical domain, please use the filter feature of the **PLECS Demo Models** library.

5 Bibliography

[1] Pacejka, H.B, *Tire and Vehicle Dynamics*, 3rd Edition, Butterworth-Heinemann, Oxford, 2012, Chapters: 1, 4, 7, and 8.

Revision History:

PLECS 4.3.1	First release

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