Ansys 2025 R2

POWERING INNOVATION THAT DRIVES HUMAN ADVANCEMENT

Twin Builder® Components: HEV VHDLAMS

Ansys

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1 - HEV VHDLAMS Library

The components in the HEV VHDLAMS library are mostly first principle mathematical system-level models. The library has two main objectives:

- Provide reusable and extensible generic components for further customer design
- Provide demonstrative example applications that use these generic components

The HEV VHDLAMS library consists of the following types of components:

- Data and Control
- Electrical
- Mechanical

The following applications are constructed with the generic component models:

- Conventional Vehicle (CV)
- Electrical Vehicle (EV)
- Hybrid Electrical Vehicle (HEV)
- Hybrid Electrical Vehicle (HEV) with Permanent Magnet Synchronous Motor (PMSM)

Data and Control Components

The Data and Control components consist of the following types of models:

- C Controller CV
- C Controller EV
- C Controller HEV
- Driver HEV
- Motor Controller HEV
- PMSM Controller HEV

c_controller_cv: CV central controller model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

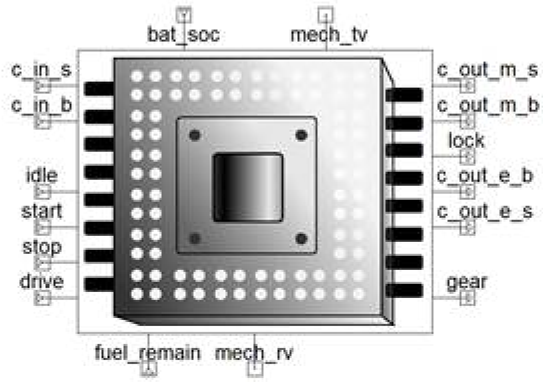

Figure 1. Component symbol

Description

The *central controller* is the main controller to handle the control signal distribution. One of its functions is to define the power distribution of the mechanical and electrical propulsion and braking system. In this model, disabled the electrical powertrain line after the start period, which achieves the conventional vehicle. It is very easy for the user to customize the control strategy in different test case scenarios.

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Name	Port/Terminal Description	Nature/Data Type
mech_rv (See Note)	Connect to engine. Transfer engine rotational speed to central controller	rotational_velocity
mech_tv (See Note)	Connect to chassis. Transfer the calculated vehicle speed to central controller	translational_velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
bat_ub	Battery upper limit for engine on/off control	Real	0.70
bat_lb	Battery lower limit for engine on/off control	Real	0.50

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
c_in_s	Input control signal for vehicle speed up	Input	Real
c_in_b	Input control signal for vehicle brake	Input	Real
c_out_e_s	Output control signal for vehicle speed up, to mechanical powertrain	Output	Real
c_out_e_b	Output control signal for vehicle brake, to mechanical powertrain	Output	Real
c_out_m_s	Output control signal for vehicle speed up, to electrical powertrain	Output	Real
c_out_m_b	Output control signal for vehicle brake, to electrical powertrain	Output	Real
fuel_remain	Input quantity shows the fuel remaining in the fuel tank	Input	Real
bat_soc	Input quantity shows battery soc	Input	Real
gear (signal)	Output gear level signal	Output	natural
start (signal)	Input start information signal	Input	Boolean
stop (signal)	Input stop information signal	Input	Boolean
drive (signal)	Input drive information signal	Input	Boolean
idle (signal)	Input idle information signal	Input	Boolean
lock (signal)	Output lock signal to clutch	Output	Boolean

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References

Ehsani, M., Y. Gao and A. Emadi. 2010. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles - Fundamentals, Theory, and Design*. 2nd ed. CRC Press, Boca Raton, FL: Taylor and Francis

Group, LLC.

c_controller_ev: EV central controller model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

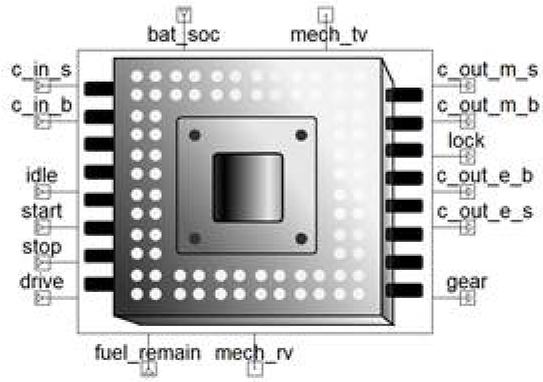

Figure 1. Component symbol

Description

The *central controller* is the main controller to handle the control signal distribution. One of its functions is to define the power distribution of the mechanical and electrical propulsion and braking system. In this model, represents the control for a pure electrical vehicle. It is very easy for the user to customize the control strategy in different test case scenarios.

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Input/Output Quantities

Table 1

Name	Description [Unit]	Direction	Data Type
c_in_s	Input control signal for vehicle speed up	Input	Real
c_in_b	Input control signal for vehicle brake	Input	Real
c_out_m_s	Output control signal for vehicle speed up, to electrical powertrain	Output	Real
c_out_m_b	Output control signal for vehicle brake, to electrical powertrain	Output	Real
bat_soc	Input quantity shows battery soc	Input	Real
start (signal)	Input start information signal	Input	Boolean
stop (signal)	Input stop information signal	Input	Boolean
drive (signal)	Input drive information signal	Input	Boolean
idle (signal)	Input idle information signal	Input	Boolean
lock (signal)	Output lock signal to clutch	Output	Boolean

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References

Ehsani, M., Y. Gao and A. Emadi. 2010. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles - Fundamentals, Theory, and Design*. 2nd ed. CRC Press, Boca Raton, FL: Taylor and Francis Group, LLC.

c_controller_hev: HEV central controller

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

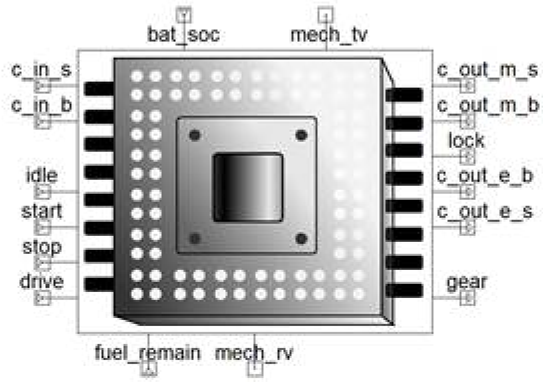

Figure 1. Component symbol

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Description

The *central controller* is the main controller to handle the control signal distribution. One of its functions is to define the power distribution of the mechanical and electrical propulsion and braking system. In this model, a simple engine on-off control is implemented to achieve simple HEV control strategy. It is very easy for the user to customize the control strategy in different test case scenarios.

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Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_rv (See Note)	Connect to engine. Transfer engine rotational speed to central controller	rotational_velocity
mech_tv (See Note)	Connect to chassis. Transfer the calculated vehicle speed to central controller	translational_velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
bat_ub	Battery upper limit for engine on/off control	Real	0.70
bat_lb	Battery lower limit for engine on/off control	Real	0.50

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
c_in_s	Input control signal for vehicle speed up	Input	Real
c_in_b	Input control signal for vehicle brake	Input	Real
c_out_e_s	Output control signal for vehicle speed up, to mechanical powertrain	Output	Real
c_out_e_	Output control signal for	Output	Real

b	vehicle brake, to mechanical powertrain		
c_out_m_s	Output control signal for vehicle speed up, to electrical powertrain	Output	Real
c_out_m_b	Output control signal for vehicle brake, to electrical powertrain	Output	Real
fuel_remain	Input quantity shows the fuel remaining in the fuel tank	Input	Real
bat_soc	Input quantity shows battery soc	Input	Real
gear (signal)	Output gear level signal	Output	natural
start (signal)	Input start information signal	Input	Boolean
stop (signal)	Input stop information signal	Input	Boolean
drive (signal)	Input drive information signal	Input	Boolean
idle (signal)	Input idle information signal	Input	Boolean
lock (signal)	Output lock signal to clutch	Output	Boolean

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References

Ehsani, M., Y. Gao and A. Emadi. 2010. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles - Fundamentals, Theory, and Design*. 2nd ed. CRC Press, Boca Raton, FL: Taylor and Francis Group, LLC.

driver_hev: Driver model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

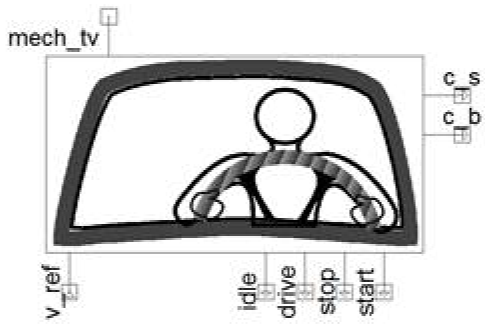

Figure 1. Component symbol

Description

The driver model represents the velocity tracking behavior, which is used to minimize the difference between vehicle velocity reference and the actual system-calculated vehicle velocity. Two PI controllers are used to generate the control signals for propulsion and brake operations separately. The driver also needs to indicate what condition the vehicle is in (for example, start, drive, stop, idle) to help other controllers or components to take different behaviors in different stages.

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Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_tv (See Note)	Connect to chassis, to obtain actual model calculated vehicle velocity	translational_ velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value[Unit]
kp_s	Coefficient for proportional control of vehicle speeds up	Real	0.2
ki_s	Coefficient for integral control of vehicle speeds up	Real	0.01
kp_b	Coefficient for proportional control of vehicle brake	Real	0.2
ki_b	Coefficient for integral control of vehicle brake	Real	0.02

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
v_ref	Reference speed input [m/s]	Input	Real
c_s	Output control signal for vehicle speed up	Output	Real
c_b	Output control signal for vehicle brake	Output	Real
start (signal)	Signal to indicate if the vehicle is in start period	Output	Boolean
stop (signal)	Signal to indicate if the vehicle is in stop period	Output	Boolean
drive (signal)	Signal to indicate if the vehicle is in driving stage	Output	Boolean
idle (signal)	Signal to indicate if the vehicle is in idle stage	Output	Boolean

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References

Ehsani, M., Y. Gao and A. Emadi. 2010. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles - Fundamentals, Theory, and Design*. 2nd ed. CRC Press, Boca Raton, FL: Taylor and Francis Group, LLC.

motor_controller_hev: Motor controller model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

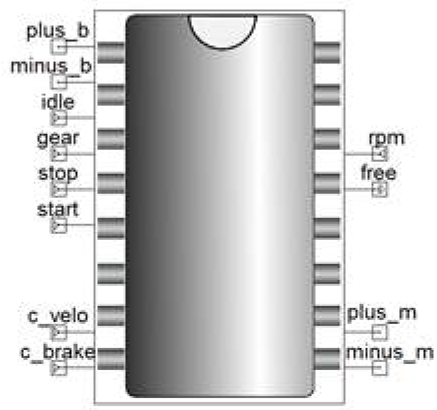

Figure 1. Component symbol

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Description

The *motor controller* model represents the system-level behavioral description of current control of the DC motor. A desired torque is calculated based on input control signal. The desired current to the motor is then derived based on mechanical and electrical energy conversion with estimated motor rotational velocity. The voltage provided to the DC motor is related to the battery voltage, which depends on the battery SOC. The battery is discharged when the DC motor speeds up and charged when the DC motor slows down.

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
plus_m (See Note)	Node plus (connect to motor)	electrical
minus_m (See Note)	Node minus (connect to motor)	electrical
plus_b (See Note)	Node plus (connect to battery)	electrical
minus_b (See Note)	Node minus (connect to battery)	electrical

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value[Unit]
p_forward	Power can be provided for increasing motor speed	Real	300.0 [kw]
p_backward	Power can be provided for decreasing motor speed	Real	300.0 [kw]
n_forward	Base rotational speed for increasing motor speed	Real	2000.0 [rpm]
n_backward	Base rotational speed for decreasing motor speed	Real	2000.0 [rpm]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
c_velo	Control value for increasing motor speed	Input	Real
c_brake	Control value for decreasing motor speed	Input	Real
rpm	Estimated motor speed	Input	Real
gear (signal)	Gear information	Input	natural
start (signal)	Start period information	Input	Boolean
stop (signal)	Vehicle stopping information	Input	Boolean
idle (signal)	System idle information	Input	Boolean
free (signal)	Free signal to motor	Output	Boolean

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pmsm_controller_hev: Model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

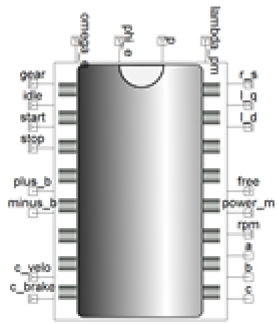

Figure 1. Component symbol

Description

The *pmsm controller* model represents the system-level behavioral description of the pmsm motor controller. A desired torque is calculated based on the input control signal. The desired current to the motor is then derived based on mechanical and electrical energy conversion with estimated motor rotational velocity. The voltage provided to the pmsm motor is related to the battery voltage (which depends on the battery SOC). The battery will be discharged when the pmsm motor speeds up and will be charged when the pmsm motor slows down.

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
a (See Note)	Node a (connect to motor)	electrical
b (See Note)	Node b (connect to motor)	electrical
c (See Note)	Node c (connect to motor)	electrical
plus_b (See Note)	Node plus (connect to battery)	electrical
minus_b (See Note)	Node minus (connect to battery)	electrical

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value[Unit]
p_forward	Power can be provided for increasing motor speed	Real	300.0 [kw]
p_backward	Power can be provided for decreasing motor speed	Real	300.0 [kw]
n_forward	Base rotational speed for increasing motor speed	Real	2000.0 [rpm]
n_backward	Base rotational speed for decreasing motor speed	Real	2000.0 [rpm]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
c_velo	Control value for increasing motor speed	Input	Real
c_brake	Control value for decreasing motor speed	Input	Real

rpm	Estimated motor speed	Input	Real
power_m	Motor power	Input	Real
omega_e	Motor electrical rotational	Input	Real
phi_e	Motor electrical rotational	Input	Real
p	Motor pole	Input	Real
r_s	Stator resistance	Input	Real
l_d	Inductance of stator of motor, d axis	Input	Real
l_q	Inductance of stator of motor, q axis	Input	Real
lambda_pm	Mutual flux linkage of motor	Input	Real
gear (Signal)	Gear information	Input	Natural
start (Signal)	Start period information	Input	Boolean
stop (Signal)	Vehicle stopping information	Input	Boolean
idle (Signal)	System idle information	Input	Boolean
free (Signal)	Free signal to motor	Output	Boolean

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Electrical Components

The Electrical components consist of the following types of models:

- DC EM HEV
- PMSM_HEV

dc_em_hev: Permanent magnet DC motor (PMDC) model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

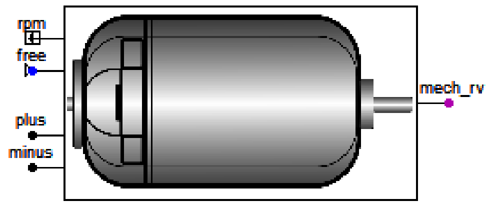

Figure 1. Component symbol

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Description

The *electrical motor* model represents the mathematical modeling of the permanent magnet DC motor (PMDC).

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Assumptions and Limitations

The model describes the system-level behavioral performance of a DC motor. No detailed geometry-based modeling is involved. The nonlinear magnetic circuit is able to consider the dependence on excitation flux and inductance caused by the excitation current. Armature and exciter circuit of the DC machine model are considered to be completely decoupled. No friction loss is considered and no consideration is given of armature reaction on exciting field.

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Mathematical Description

The voltage across the DC motor can be given by using Kirchoff’s law:

$$V_m = R_a i_m + L_a \frac{di_m}{dt} + V_{emf}$$

where R_a is the armature resistance, L_a is the armature inductance, V_{emf} is the back emf of the motor and *im* is the current through the DC motor. The generated motor torque can be given approximately by

$$T_m = k_i \cdot i_m$$

where k_i is the so-called motor torque constant. The back emf is also related to the mechanical part by

$$V_{emf} = k_e \omega_m$$

where k_e is the back emf constant, *ï‰*$_m$ is the rotational velocity of the motor. The motor dynamics is represented by

$$T_m = J\dot{\omega}_m + b\omega_m$$

where *J* is the system inertia, *b* is the friction coefficient. The system inertia is evaluated during the entire system simulation, and it changes when vehicle conditions change.

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Table 1

Name	Port/Terminal Description	Nature/Data Type
plus (See Note)	Node plus	electrical
minus (See Note)	Node minus	electrical
mech_rv (See Note)	Mechanical node	rotational_velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
l_a	Armature inductance	inductance	0.0095 [L]

r_a	Armature/rotor res-istance	resistance	1.2 [Ohm]
coe_t	Motor torque constant	Real	100.0
coe_e	Back emf constant	Real	100.0
coe_b	Viscous damping coef-ficient	Real	0.01
i_a0	Initial current	current	0.0 [A]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
free (sig-nal)	Input signal to indicate if the motor is on	Input	Boolean
rpm	Motor rotational rpm	Output	Real

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References

Wolm, P., X.Q. Chen, J.G. Chase, W. Pettigrew and C.E. Hann. 2008. “Analysis of a PM DC Motor Model for Application in Feedback Design for Electric Powered Mobility Vehicles.” In the 15th International Conference on Mechatronics and Machine Vision in Practice, Auckland, New Zealand.

pmsm_hev: Dynamic Model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

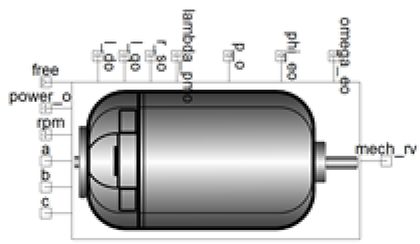

Figure 1. Component symbol

Description

The *pmsm_hev* model represents the dynamic behavior of a permanent magnet synchronous motor (PMSM).

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Assumptions and Limitations

The model describes the system-level behavioral performance of a PMSM motor. No detailed geometry-based modeling is involved.

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Mathematical Description

Electrical and mechanical angle relation:

$$\theta_e = \frac{p}{2} \cdot \theta_m$$

$$\omega_e = \frac{p}{2} \cdot \omega_m$$

Park's Transformation:

$$V_a = \cos(\theta_e) \cdot V_d - \sin(\theta_e) \cdot V_q + V_0$$

$$V_b = \cos\left(\theta_e - \frac{2}{3}\pi\right) \cdot V_d - \sin\left(\theta_e - \frac{2}{3}\pi\right) \cdot V_q + V_0$$

$$V_c = \cos\left(\theta_e + \frac{2}{3}\pi\right) \cdot V_d - \sin\left(\theta_e + \frac{2}{3}\pi\right) \cdot V_q + V_0$$

$$I_a = \cos(\theta_e) \cdot I_d - \sin(\theta_e) \cdot I_q + I_0$$

$$I_b = \cos\left(\theta_e - \frac{2}{3}\pi\right) \cdot I_d - \sin\left(\theta_e - \frac{2}{3}\pi\right) \cdot I_q + I_0$$

$$I_c = \cos\left(\theta_e + \frac{2}{3}\pi\right) \cdot I_d - \sin\left(\theta_e + \frac{2}{3}\pi\right) \cdot I_q + I_0$$

Angular velocity:

$$\frac{d\theta_m}{dt} = \omega_m$$

Dynamic equations:

$$L_d \frac{dI_d}{dt} = V_d - R_s \cdot I_d + \omega_e \cdot L_q \cdot I_q$$

$$L_q \frac{dI_q}{dt} = V_q - R_s \cdot I_q - \omega_e \cdot L_d \cdot I_d - \omega_e \cdot \lambda_{pm}$$

$$L_0 \frac{dI_0}{dt} = V_0 - R_s \cdot I_0$$

Power:

$$power = \frac{3}{2}\left(V_d I_d + V_q I_q + 2V_0 I_0\right)$$

Electrical torque:

$$\tau = \frac{3}{4} p\left(\lambda_{pm} I_q + \left(I_d - I_q\right) I_d I_q\right)$$

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Table 1

Name	Port/Terminal Description	Nature/Data Type
a (See Note)	Node a	electrical
b (See Note)	Node b	electrical
c (See Note)	Node c	electrical
mech_rv (See Note)	Mechanical node	rotational_velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value[Unit]
l_d	Inductance of stator, d axis	Real	0.042 [H]
1_q	Inductance of stator, q axis	Real	0.042 [H]
Lambda_ pm	Mutual flux linkage	Real	0.875 [H * A]
r_s	Stator resistance	Real	0.4 [Ohm]
p	Number of pole, twice of num- ber of pole pair	Real	4.0
inertia	Rotor intertia	Real	0.075 [kg * m^2]
phi_0	Initial rotor angle	Real	0.0 [rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
free (sig- nal)	Input signal to indicate if the motor is on	Input	Boolean

phi_eo	Electrical angle	Output	Real
omega_ eo	Electrical rotational speed	Output	Real
p_o	Number of pole	Output	Real
l_do	Inductance of stator, d axis	Output	Real
l_qo	Inductance of stator, q axis	Output	Real
lambda_ pmo	Mutual flux linkage	Output	Real
r_so	Stator resistance	Output	Real
power_o	Motor power	Input	Real
rpm	Motor rotational rpm	Output	Real

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Mechanical Components

The Mechanical components consist of the following types of models:

- Brake HEV
- Chassis HEV
- Clutch HEV
- Fuel Tank HEV
- Ice HEV
- Mech Coupling HEV
- Transmission HEV
- Wheel HEV

brake_hev: a single equivalent brake model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

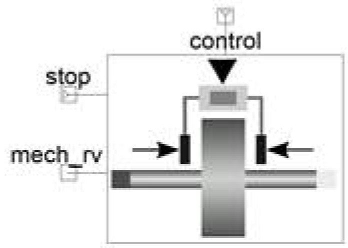

Figure 1. Component symbol

Description

The brake model describes the performance of the vehicle brake system based on a single state hydraulic model. In the model, a single equivalent brake model is directly represented with the connection to the primary cylinder without proportioning consideration. The dynamics from primary cylinder to deceleration of the vehicle is well considered with related empirical expressions.

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Assumptions and Limitations

The brake model is considered only in a so-called “quarter car” model. The vehicle is supposed to only move forward without any consideration of turning around. The force distribution among individual wheels is not considered. Geometry structure is not considered in detail. Only a single state model with connected equivalent brake and primary cylinder is considered.

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Mathematical Description

The brake model describes the performance of the vehicle brake system. The pressure in the primary cylinder can be described as:

$$P_{mc} = \left(F_{in} - F_{cs} - F_{cf} \right) / A_{mc}$$

where F_{in} is the input force to the brake system, given by

$$F_{in} = c_s \cdot f_{max}$$

where c_s is the control signal from the controller, f_{max} is the maximum force can be provided. F_{cs} is the primary cylinder spring pre-load, F_{cf} is the seal friction in the cylinder and *Amc* is the area of primary cylinder. The dynamics of the volume of displaced brake fluid can be given by

$$\dot{V}_b = \operatorname{sgn}\left(P_{mc} - P_w \right) c_q \sqrt{\left| P_{mc} - P_w \right|}$$

where c_q is the effective flow coefficient and the lumped fluid capacity of the brake system is given by

$$P_w = 23.4375 \cdot V_b^3 + 89.0625 \cdot V_b^2 + 356.25 \cdot V_b$$

And the output torque can be given by

$$T_b = \begin{cases} k_b \left(P_w - P_{po} \right) & \text{if } P_w \geq P_{po} \\ 0 & \text{otherwise} \end{cases}$$

with k_b=*1.05* and P_{po}=*5.7143*.

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Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_rv (See Note)	Rotational velocity node, connect to wheel	rotational_ velocity

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Parameters

Table 2

Name	Description	Data Type	Default Value[Unit]
f_max	Maximum input force for brake	Real	350.0 [N]
f_cs	Primary cylinder spring pre-load	Real	1.38 [N]
f_cf	Seal friction in the cylinder	Real	0.8 [N]
area_mc	Area of the primary cylinder	Real	4.91E-4 [m^2]
c_q	Effective flow coefficient	Real	0.933 [cm^3/s (kPa)^-2]
coef_b	Tuning coefficient for brake force	Real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
control	Break control signal	Input	Real
stop (signal)	Vehicle stopping information	Input	Boolean
idle (signal)	System idle information	Input	Boolean

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References

Hedrick, J.K., J.C. Gerdes, D.B. Maciuca and D. Swaroop. 1997. “Brake System Modeling, Control and Integrated Brake/Throttle Switching: Phase I.” California PATH Research Report, UCB-ITS-PRR, Institute of Transportation studies (UCB), UC Berkeley, Berkeley, California.

chassis_hev: The vehicle body (chassis) model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

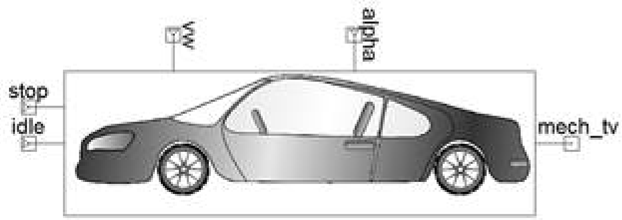

Figure 1. Component symbol

Description

The vehicle body (chassis) model simply describes the performance of the vehicle body with consideration of rolling resistance, aerodynamic drag, grading resistance and dynamic behavior of the chassis. The vehicle velocity is always assumed as zero or positive in this model.

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Assumptions and Limitations

Top

Mathematical Description

The chassis dynamics can be presented as

$$m_{veh}\frac{dv_{veh}}{dt} = f_{veh} + \left(f_{rol} + f_{wind}\right)\cdot \mathrm{sgn}\left(v_{veh}\right) + f_{grad}$$

where m_{veh} is the mass of the vehicle and f_{veh} is the force from wheel; the rolling force can be given by

$$f_{rol} = m_{veh} \cdot g \cdot c_{rr} \cos(\alpha)$$

where the rolling resistance coefficient can be obtained by:

$$c_{rr} = 0.01 \cdot \frac{1 + v_{veh}}{160}$$

The aerodynamic drag force from wind can be given by

$$f_{wind} = \frac{1}{2} \rho_{air} A_{front} c_{drag} (v_{veh} - v_{wind})^2$$

where ρ_{air} is the air density, A_{front} is the vehicle front projection area, c_{drag} is the air drag coefficient and v_{wind} is the wind velocity. The grading force can be obtained by

$$f_{grad} = m_{veh} \cdot g \cdot \sin(\alpha)$$

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Netlist Syntax

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_tv (See Note)	Translational velocity node, connect to wheel and driver	translational_ velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
mass	Vehicle mass, must equal to the parameter used in wheel	Real	1520.0 [kg]
rho	Air density	Real	1.259 [kg/m^3]

a_f	Front projection area	Real	1.70 [m^2]
c_d	Drag coefficient	Real	0.45

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
alpha	Grading angle [deg]	Input	Real
vw	Air velocity parallel to the vehicle velocity, positive when in the same direction of the vehicle [m/s]	Input	Real
stop (signal)	Vehicle stopping information	Input	Boolean
idle (signal)	System idle information	Input	Boolean

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References

1. Ehsani, M., Y. Gao and A. Emadi. 2010. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles - Fundamentals, Theory, and Design*. 2nd ed. CRC Press, Boca Raton, FL: Taylor and Francis Group, LLC.
2. Nobrant, P. 2001. “Driveline Modeling Using MathModelica.” Master's Thesis, Vehicular Systems, Department of Electrical Engineering, Linköpings Institute of Technology, Linköping and Norrköping, Sweden.

clutch_hev: Clutch model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

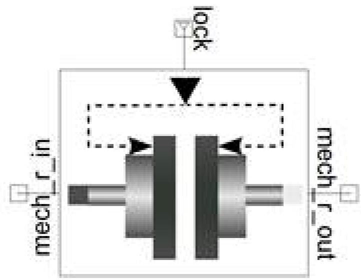

Figure 1. Component symbol

- Description
- Assumptions and Limitations
- Mathematical Description
- Netlist Syntax
- Conservative Pins
- Parameters
- Input/Output Quantities
- Example
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Description

This clutch model describes a simple behavior of clutch based on the control signal LOCK from the controller. When LOCK is TRUE, then the torque and rotational velocity are fully transferred; otherwise, the torque and rotational velocity are not transferred.

Top

Assumptions and Limitations

Assume ideal transfer of torque and rotational velocity in the clutch. No loss is considered.

Top

Mathematical Description

If LOCK is TRUE

$$\tau_a + \tau_b = 0$$
$$\omega_a = \omega_b$$

Else

$$\tau_b = 0$$
$$\omega_a = 0$$

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Netlist Syntax

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_r_a (See Note)	Port connects to engine	rotational_velo-city
mech_r_b (See Note)	Port connects to trans-mission	rotational_velo-city

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
lock (sig-nal)	Control signal to indicate the clutch is lock or not	Input	Boolean

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References

fuel_tank_hev: Fuel tank model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

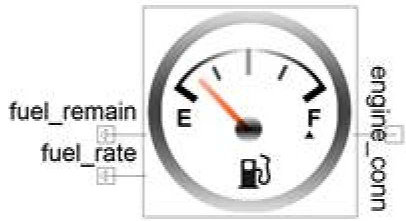

Figure 1. Component symbol

Description

The fuel tank model is a tank model to represent the fuel consumption rate and the fuel remaining in the tank.

Top

Assumptions and Limitations

1. The fuel tank model does not treat “full” or “empty” conditions directly for connected external components. The signals indicating “full” or “empty” conditions will go to the controller to make further decision.
2. Warnings will also come out when the fuel tank is full or empty.

Top

Mathematical Description

The fuel consumption rate can be given by

$$FR = \frac{\dot{m}_{fuel}}{\rho_{fuel} \cdot V_{tank}}$$

where $\dot{m}_{fuel}$ is the mass flow rate of fuel consumption estimated from ICE model. ρ_{fuel} is the fuel density and V_{tank} is the volume of the fuel tank.

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Netlist Syntax

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
engine_conn (See Note)	Connect to engine, transfer the mass flow rate of fuel consumption estimated by internal combustion engine model	compressible_fluidic

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

Top

Parameters

Table 2

Name	Description	Data Type	Default Value[Unit]
fuel_remain0	Initial fuel level in the tank (0 <= fuel_remain0 <= 1)	Real	1.0
rho	Gasoline density	Real	719.0 [kg/m^3]
v	Total volume of the fuel tank	Real	0.015 [m^3]
fuel_limit_low	Fuel level lower limitation	Real	0.1
fuel_limit_high	Fuel level upper limitation	Real	1.1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
fuel_ remain	Percentage of fuel remaining in the tank	Output	Real
fuel_rate	Fuel consumption rate [kg/s]	Output	Real

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References

ice_hev: So-called mean value internal combustion engine model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

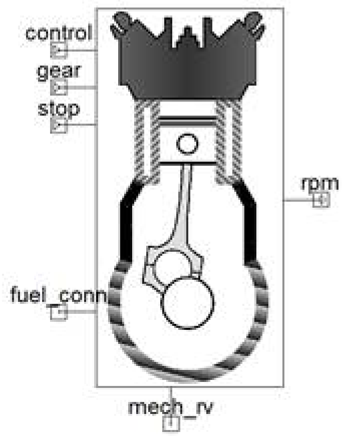

Figure 1. Component symbol

Description

This engine model is a so-called mean-value internal combustion engine model. It mainly contains three components: throttle body, intake manifold and engine. Three main dynamics are discussed: air dynamics, fuel dynamics and rotational dynamics.

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Assumptions and Limitations

1. The air filter effect is neglected.
2. The engine is naturally aspirated.
3. The intake manifold system is isothermal.
4. Minor component effects are not modeled.
5. The system is continuous.

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Mathematical Description

It is mainly composed by three components, including throttle body, intake manifold and engine cylinder. The air mass flow rate throttled into engine can be given by

$$\dot{m}_{thr} = \dot{m}_{\max} \cdot A_{thr} \cdot f\left(\frac{P_{im}}{P_{atm}}\right)$$

where $\dot{m}_{\max}$ is the maximum air mass flow rate with an entirely opened throttle. A_{thr} is the normalized throttle area can be given by

$$A_{thr} = \begin{cases} -\frac{d \cdot D}{2}\sqrt{1-a^2} + \frac{d \cdot D}{2}\sqrt{1-\left(a\frac{\cos\varphi_0}{\cos\varphi}\right)^2} + \frac{D^2}{2}\arcsin\sqrt{1-a^2} - & \\ \frac{D^2}{2}\frac{\cos\varphi}{\cos\varphi_0}\arcsin\sqrt{1-\left(a\frac{\cos\varphi_0}{\cos\varphi}\right)^2} & \text{if } \varphi < \arccos(a\cos\varphi_0) - \varphi_0 \\ \frac{D^2}{2}\arcsin\sqrt{1-a^2} - \frac{d \cdot D}{2}\sqrt{1-a^2} & \text{otherwise} \end{cases}$$

where d is the throttle pin diameter, D is the throttle bore and $a = d/D$; φ and φ_0 are the throttle angle and the throttle angle at closed position, respectively. The pressure ratio can be given by

$$f\left(\frac{P_{im}}{P_{atm}}\right) = \begin{cases} 2\sqrt{\frac{P_{im}}{P_{atm}} - \left(\frac{P_{im}}{P_{atm}}\right)^2} & \text{if } P_{im} > \frac{P_{atm}}{2} \\ 1 & \text{otherwise} \end{cases}$$

The air dynamics in the intake manifold can be given by

$$\frac{dm_{im}}{dt} = \dot{m}_{thr} - \dot{m}_e$$

With isothermal assumption, we have

$$T_{thr} = T_{im} \text{ and } P_{im} = \frac{RT_{im}}{V_{im} m_{im}}$$

where *R* is the gas constant. The mass flow rate to the engine is

$$\dot{m}_e = \frac{n_{cyl}\eta_{vol} m_{im}\omega_e V_d}{4\pi V_{im}}$$

where n_{cyl} is the number of cylinders, ω_e is the engine rotational velocity, V_d is the cylinder displacement volume. η_{vol} is the volumetric efficiency of engine, can be given by

$$\eta_{vol} = \left(24.5\omega_e - 3.1\times10^4\right)m_{im}^2 + \left(-0.167\omega_e + 222\right)m_{im} + \left(8.1\times10^{-4}\omega_e + 0.352\right)$$

The fuel dynamics are described as

$$\tau_f \ddot{m}_{fi} + \dot{m}_{fi} = \dot{m}_{fc} = \frac{\dot{m}_e}{r_{AF}}$$

where τ_f is the fueling time constant. $\dot{m}_{fc}$ and $\dot{m}_{fi}$ are the requested and actual fuel mass flow rate, respectively. r_{AF} is the air/fuel ratio into the engine. The engine rotational dynamics can be described as

$$J_e\dot{\omega}_e = T_i - T_f - T_p$$

where J_e is the engine inertia; T_i is the engine indicated torque given by

$$T_i = c_T \frac{\dot{m}_e}{\omega_e}\cdot c_{AFI}\cdot c_{SI}$$

where c_T is the maximum torque constant of engine for specified $\dot{m}_e$. c_{AFI} is the normalized air fuel influence coefficient given by

$$c_{AFI} = \cos\left(7.3834\left(r_{AF} - 13.5\right)\right)$$

c_{SI} is the normalized spark influence coefficient given by

$$c_{SI} = \left(\cos\left(SA - MBT\right)\right)^{2.875}$$

where $\left(SA - MBT\right)$ is the difference of spark advance from top dead center and the minimum spark advance for best torque. T_f is the friction torque of engine given by

$$T_f = 0.1056\omega_e$$

T_p is the engine output torque to the clutch.

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Netlist Syntax

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
fuel_conn (See Note)	Connect to fuel tank, transfer the estimated fuel consumption mass flow rate to fuel tank	compressible_ fluidic
mech_rv (See Note)	Rotational velocity connection to clutch	rotational_velo-city

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
mdot_ max	Maximum mass flow rate into throttle body	Real	0.1843 [kg/s]
d	Throttle pin diameter	Real	0.005 [m]
d_t	Throttle bore	Real	0.075 [m]
phi0	Throttle valve closed angle	Real	0.14 [rad]
tm	Intake manifold temperature	Real	300.0 [K]
vm	Intake manifold volume	Real	0.0027 [m^3]
s	Piston stroke	Real	0.1675 [m]
b	Cylinder bore	Real	0.085 [m]
n_cyl	Number of cylinders	Real	4.0
i_e	Engine inertia	Real	0.2 [kg*m^2]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
control	Control value (throttle position between 0 and 1)	Input	Real
rpm	Engine rotational rpm	Output	Real
gear (sig-nal)	Gear information	Input	natural
stop (sig-nal)	Vehicle stopping information	Input	Boolean
idle (sig-nal)	System idle information	Input	Boolean

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References

1. Saeedi, M. 2010. “A Mean Value Internal Combustion Engine Model in MapleSim.” Master's Thesis, Department of Mechanical Engineering, University of Waterloo, Ontario, Canada.
2. Samanuhut, P. 2011. “Modeling and Control of Automatic Transmission with Planetary Gears for Shift Quality.” Ph.D. Dissertation, Department of Mechanical Engineering, University of Texas at Arlington, Arlington, Texas.

mech_coupling_hev: Mechanical torque coupling model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

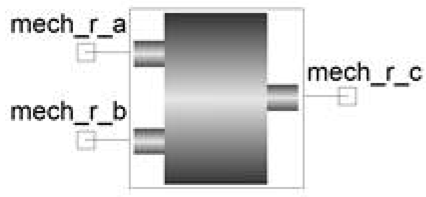

Figure 1. Component symbol

Description

The mechanical torque coupling model represents the torque coupling from the conventional powertrain line and electrical motor line.

Top

Assumptions and Limitations

The friction and power loss are not considered.

Top

Mathematical Description

The torque coupling can be given by

$$T_c + k_a \cdot T_a + k_b \cdot T_b = 0$$

where T_a, T_b and T_c are the torque from the electrical propulsion system, torque from the mechanical propulsion system and torque transfer to wheel, respectively. k_a and k_b are coefficients depending on the coupling type. For pulley or chain assembly, $k_a = r_b / r_a$ and k_b=1, where r_a and r_b are the radii of pulley a and pulley b respectively. The rotational velocities can be given by

$$k_a \cdot \omega_c = \omega_a$$
$$k_b \cdot \omega_a = k_a \cdot \omega_b$$

where ω_a, ω_b and ω_c are the rotational velocities from electrical propulsion system, mechanical propulsion system and transfer to wheel, respectively.

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Netlist Syntax

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_r_a (See Note)	Rotational velocity connection to electrical powertrain	rotational_ velocity
mech_r_b (See Note)	Rotational velocity connection to mechanical powertrain	rotational_ velocity
mech_r_c (See Note)	Rotational velocity connection to wheel	rotational_ velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value[Unit]
r_a	Radii of pully a	Real	0.1 [m]
r_b	Radii of pully b	Real	0.1 [m]

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Input/Output Quantities

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References

Ehsani, M., Y. Gao and A. Emadi. 2007. “Hybrid Electric Vehicles Architecture and Motor Drives.” IEEE Proceedings, 95(4): 719-728.

transmission_hev: Transmission model based on given data set

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

Figure 1. Component symbol

Description

The model represents the transmission performance based on given gear ratio data set. The transmission change is controlled by the control signal, which indicates the gear level.

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Assumptions and Limitations

This is a system-level behavioral transmission model. The gear ratio is selected by input gear level based on a given gear ratio data set. The power loss in transmission is represented by a transmission efficiency factor.

Top

Mathematical Description

The equations can be given by

$$\omega_a = r_{gear} \cdot \omega_b$$
$$T_a \cdot \eta_{tran} \cdot r_{gear} + T_b$$

where ω_a and T_a are the rotational velocity and torque transferred from clutch, respectively; ω_b and T_b are the rotational velocity and torque transferred to mechanical torque coupling, respectively; r_{gear} is the gear ratio selected by central controller based on vehicle condition and η_{tran} is the transmission efficiency.

The gear ratio set used is

Gear Level	0	1	2	3	4	5	6
Gear Ratio	0.0	4.61	3.03	1.986	1.428	1.0	0.737

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Netlist Syntax

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_r_a (See Note)	Connect to clutch	rotational_velocity
mech_r_b (See Note)	Connect to mechanical coupling	rotational_velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
eta_tran	Transmission efficiency factor	Real	0.95

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
control_ tran (sig- nal)	Control signal for gear level change (between 0 and 6)	Input	natural

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References

Ehsani, M., Y. Gao and A. Emadi. 2007. "Hybrid Electric Vehicles Architecture and Motor Drives." IEEE Proceedings, 95(4): 719-728.

wheel_hev: Wheel model

Library: HEV VHDLAMS	Modeling Language: VHDL-AMS	Version Number: Twin Builder 2025.2

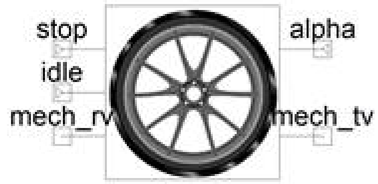

Figure 1. Component symbol

Description

The *wheel* model describes the longitudinal direction wheel dynamics as well as the slip. The relation between friction and the slip is provided by empirical function. Only one wheel is considered in the modeling for simplicity (the so-called quarter car model). The rolling resistance is moved to the chassis (vehicle body) part, together with all other driving resistance.

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Assumptions and Limitations

Top

Mathematical Description

The slip ratio can be calculated as

$$\lambda = \begin{cases} (v_w - v_{veh})/v_w & \text{if } \dot{v}_{veh} > 0 \\ (v_w - v_{veh})/v_{veh} & \text{otherwise} \end{cases}$$

Where $v_w = \omega_w \cdot r_w$ with ω_w as the wheel rotational velocity and r_w as the wheel radius. The wheel dynamics can be presented as

$$J_w \frac{d\omega_w}{dt} = T_w + r_w \cdot f_{long}$$

where J_w is the inertia of the wheel, T_w is the torque from mechanical coupling and f_{long} is the longitudinal wheel friction force, which can be further obtained by

$$f_{long} = \left(d_x \sin\left(c_x \arctan(b_x \phi)\right) + s_{vx}\right) \cdot \cos(\alpha)$$

where b_x, $c_x d_x$ and s_{vx} are all fitted wheel constant. α is the grading angle and ϕ can be obtained from

$$\phi = (1 - e_x)(\lambda + S_{hx}) + \frac{e_x}{b_x} \arctan\left(b_x(\lambda + S_{hx})\right)$$

where e_x and S_{hx} are constants fitted from test data.

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Netlist Syntax

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
mech_rv (See Note)	Rotational velocity node, connect to mechanical coupling	rotational_velocity
mech_tv (See Note)	Translational velocity node, connect to chassis	translational_velocity

Note: Terminal set to No Action when unconnected. Terminal may remain unconnected without generating an error.

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
m_inertia	Moment of inertia of wheel	Real	0.5 [kg*m^2]

r_w	Radius of wheel	Real	0.1905 [m]
mass	Vehicle mass, must be equal to the parameter used in chassis	Real	1520.0 [kg]
b_x	Fitted empirical coefficient b_x	Real	18.6258
c_x	Fitted empirical coefficient c_x	Real	2.3132
d_x	Fitted empirical coefficient d_x	Real	37144.0
e_x	Fitted empirical coefficient e_x	Real	0.83237
s_hx	Fitted empirical coefficient s_x	Real	0.01
s_vx	Fitted empirical coefficient sv_x	Real	0.5

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
alpha	Grading angle [deg]	Input	Real
stop (signal)	Vehicle stopping information	Input	Boolean
idle (signal)	System idle information	Input	Boolean

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References

1. Yi, K. and J. Chung. 2001. “Nonlinear Brake Control for Vehicle CW/CA Systems.” IEEE/ASME Transactions on Mechatronics, 6(1): 17-25.
2. Nobrant, P. 2001. “Driveline Modeling Using MathModelica.” Master's Thesis, Vehicular Systems, Department of Electrical Engineering, Linköpings Institute of Technology, Linköping and Norrköping, Sweden.

Conventional Vehicle (CV) Application

Description

The structure of the conventional vehicle (CV) is shown in Figure 1.

Its 14 main components are:

- driving cycle
- driver
- central controller (CV)
- motor controller
- electrical motor
- battery
- internal combustion engine (ICE)
- fuel tank
- clutch
- transmission
- mechanical coupling
- brake
- wheel
- vehicle body

The CV has the same structure as the HEV. The main difference between them is that the ICE line is the only power source used to provide the propulsion and braking power when in the driving phase. The EM-Battery line is used only to help the vehicle start. In this application example, the battery is discharged only at each starting point, and then keeps the same SOC (state of charge) while the vehicle is in the driving phase (because the EM is deactivated). The fuel in the fuel tank is continuously being consumed since the ICE is in the work-alone mode.

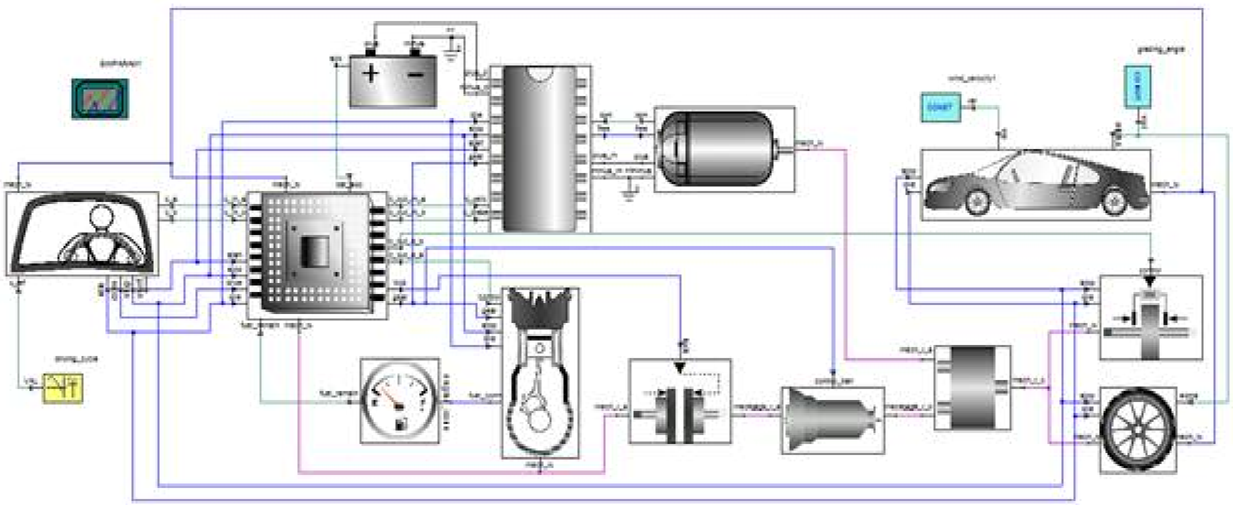

Figure 1: Conventional Vehicle Schematic

A comparison of the given reference velocity from the driving cycle and the model calculated vehicle velocity of the conventional vehicle is shown in Figure 2.

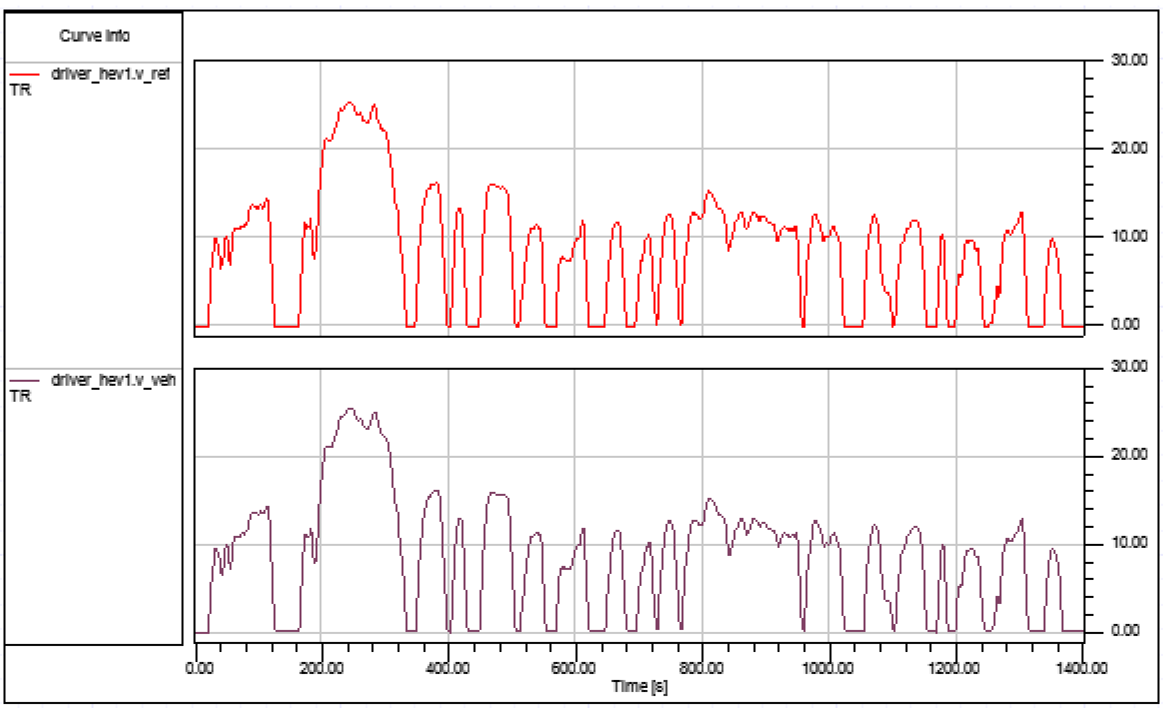

Figure 2: Given Reference Velocity vs. Model Calculated Vehicle Velocity of CV Application

The fuel remaining in the fuel tank and the change in battery state of charge (SOC) during the vehicle driving process of the CV application are shown in Figure 3. From Figure 3, it is clear that the motor line is disabled after each start period.

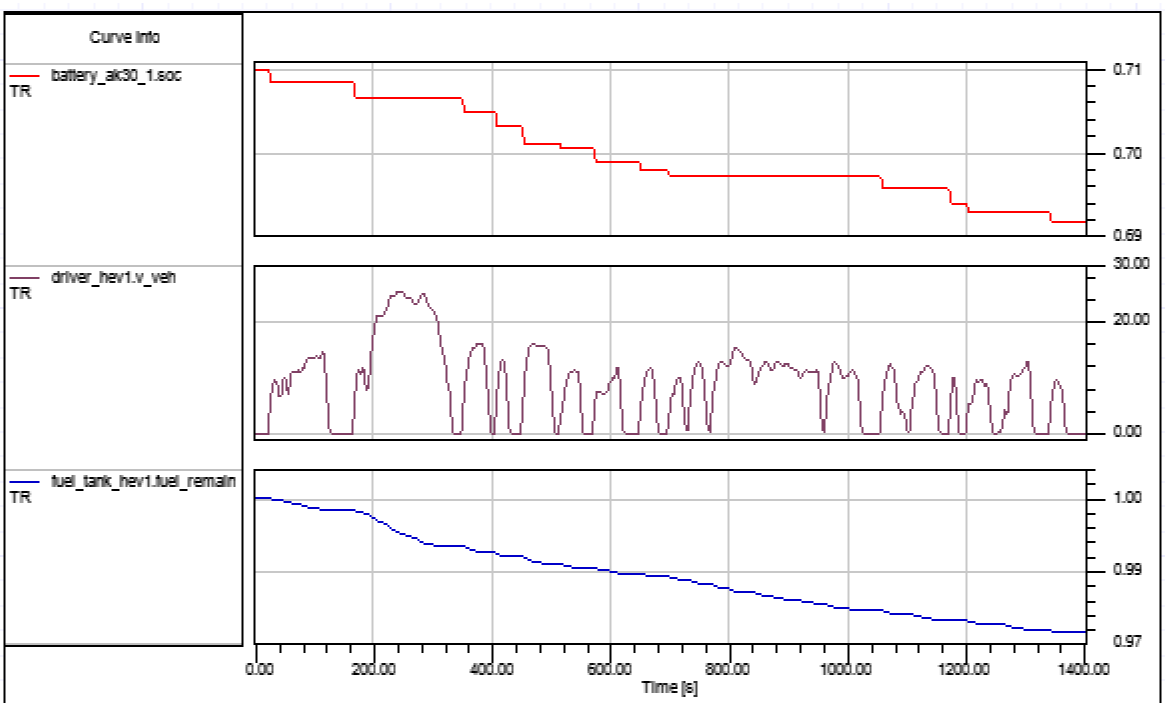

Figure 3: Model Calculated Vehicle Velocity vs. Fuel Remaining and Battery SOC of the CV Application

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Electrical Vehicle (EV) Application

Description

The structure of the purely electrical vehicle is shown in Figure 1. It is different from the CV and HEV applications in that the mechanical powertrain is removed in this application example. The electrical vehicle application contains 10 main components:

- driving cycle
- driver
- central controller (EV)
- motor controller
- electrical motor
- battery
- clutch
- brake
- wheel
- vehicle body

In this application example, the EM-Battery line is the only powertrain used to provide the propulsion and braking power in the driving phase. The battery is charged when braking, and it is discharged when providing power to propel the vehicle.

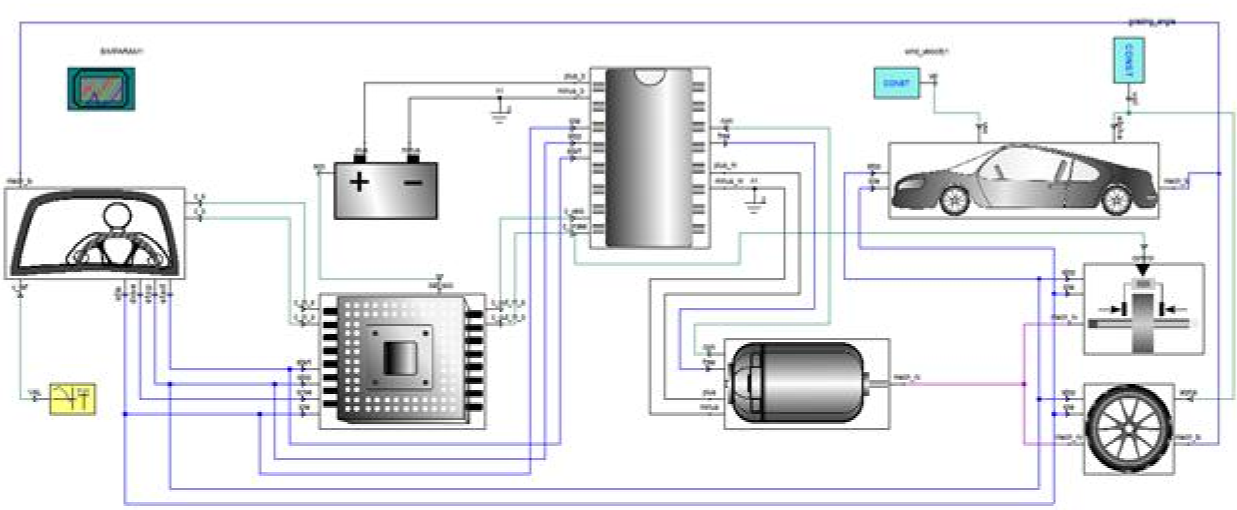

Figure 1: Electrical Vehicle Schematic

A comparison of the given reference velocity from the driving cycle and the model calculated vehicle velocity of the electrical vehicle is shown in Figure 2.

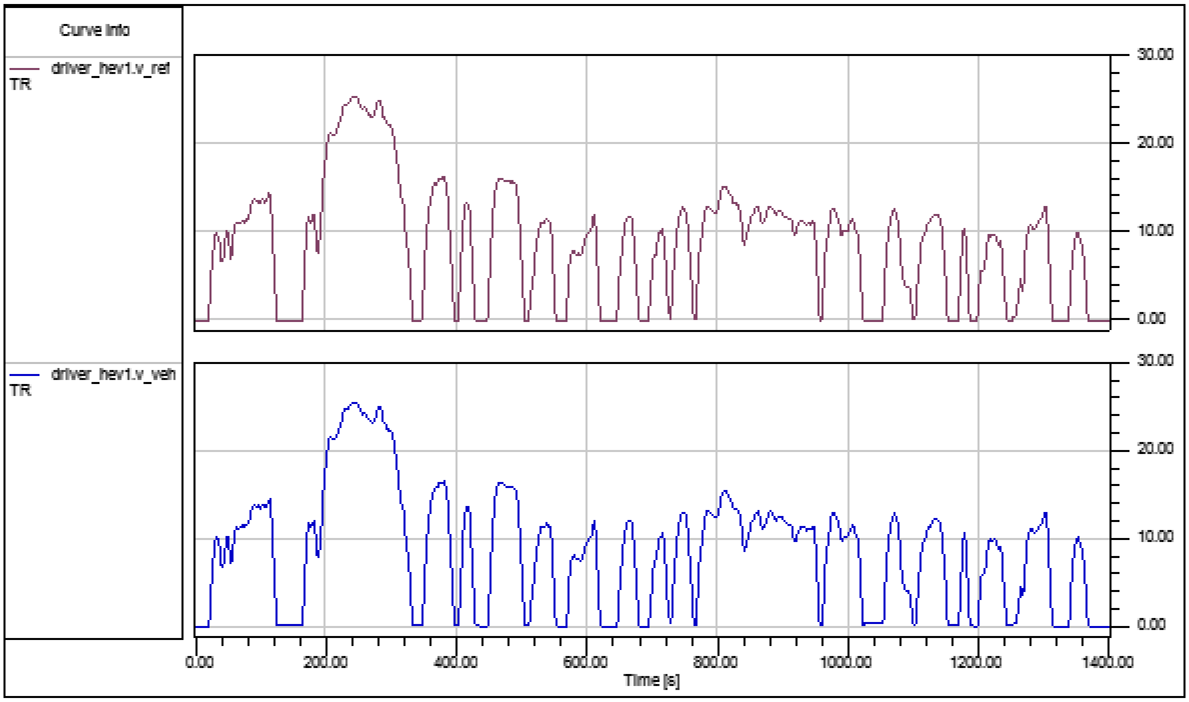

Figure 2: Given Reference Velocity vs. Model Calculated Vehicle Velocity of the EV Application.

The change of battery state of charge (SOC) during the vehicle driving process of the EV application is shown in Figure 3.

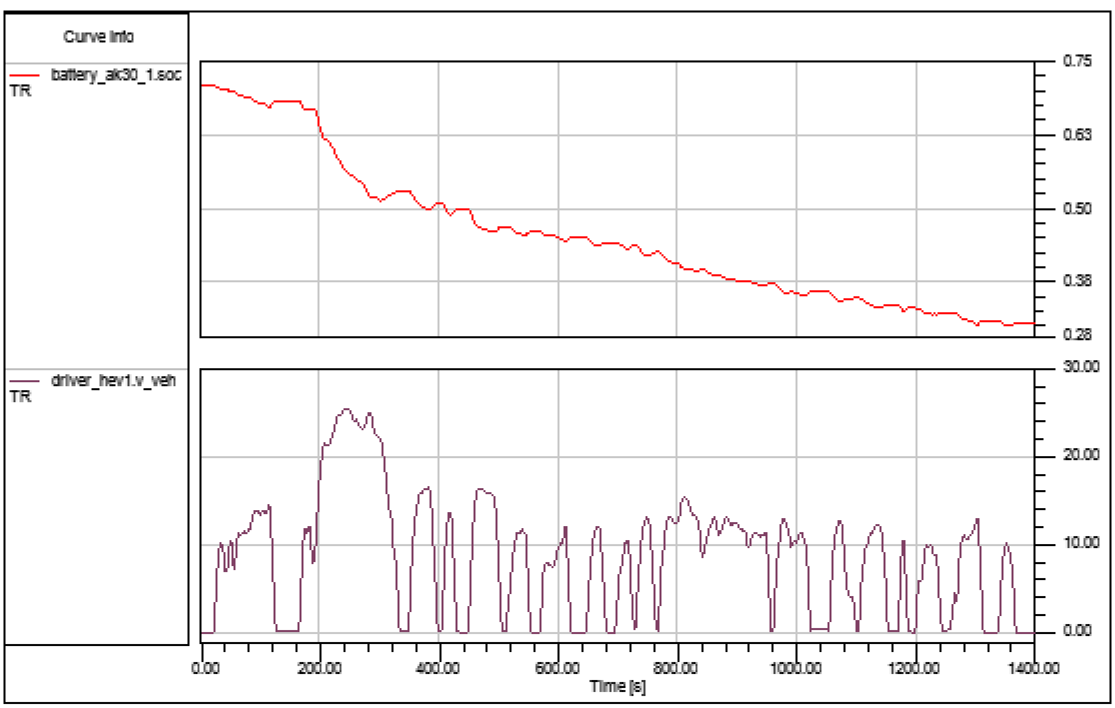

Figure 3: Model Calculated Vehicle Velocity vs. Battery SOC of the EV Application.

Top

Hybrid Electrical Vehicle (HEV) Application

Description

The hybrid electrical vehicle application schematic is shown in Figure 1.

Its main 14 components are:

- driving cycle
- driver
- central controller (HEV)
- motor controller
- electrical motor
- battery
- internal combustion engine (ICE)
- fuel tank
- clutch
- transmission
- mechanical coupling
- brake
- wheel
- vehicle body

The HEV Application example and the other applications follow the provided velocity reference from the driving cycle component. Two parallel connected powertrains (including the EM-Battery line and the conventional ICE line) are combined to provide both the propulsion and brake power of the vehicle. The fuel in the fuel tank is continuously being consumed whenever the ICE is on. The battery charges when braking, and it discharges when providing power to propel the vehicle. The power distribution follows the desired control strategy defined in the central controller component.

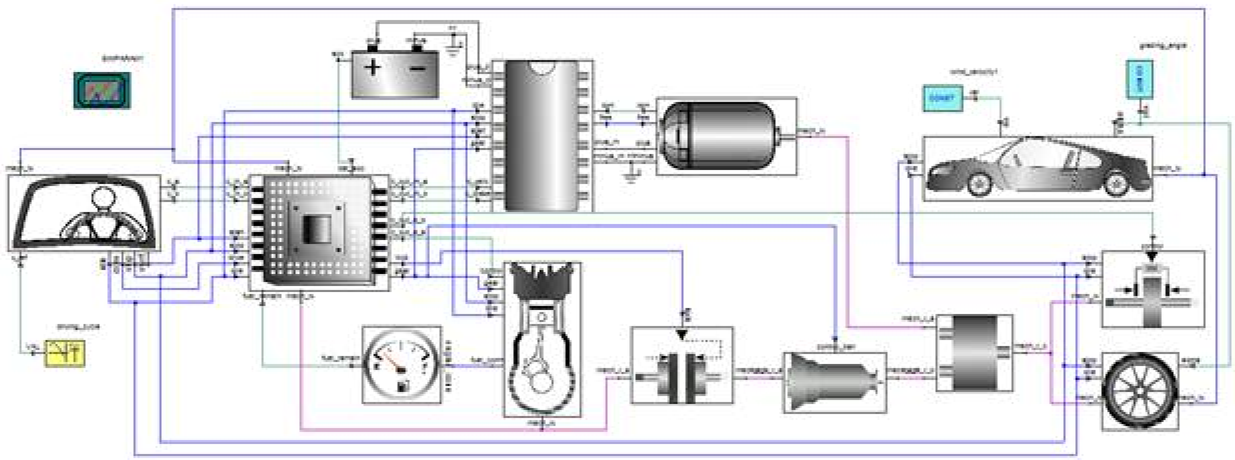

Figure 1: Hybrid Electrical Vehicle Schematic

Figure 2 shows a comparison of the given reference velocity from the driving cycle and the model calculated vehicle velocity of the hybrid electrical vehicle. The two velocities are very close to each other.

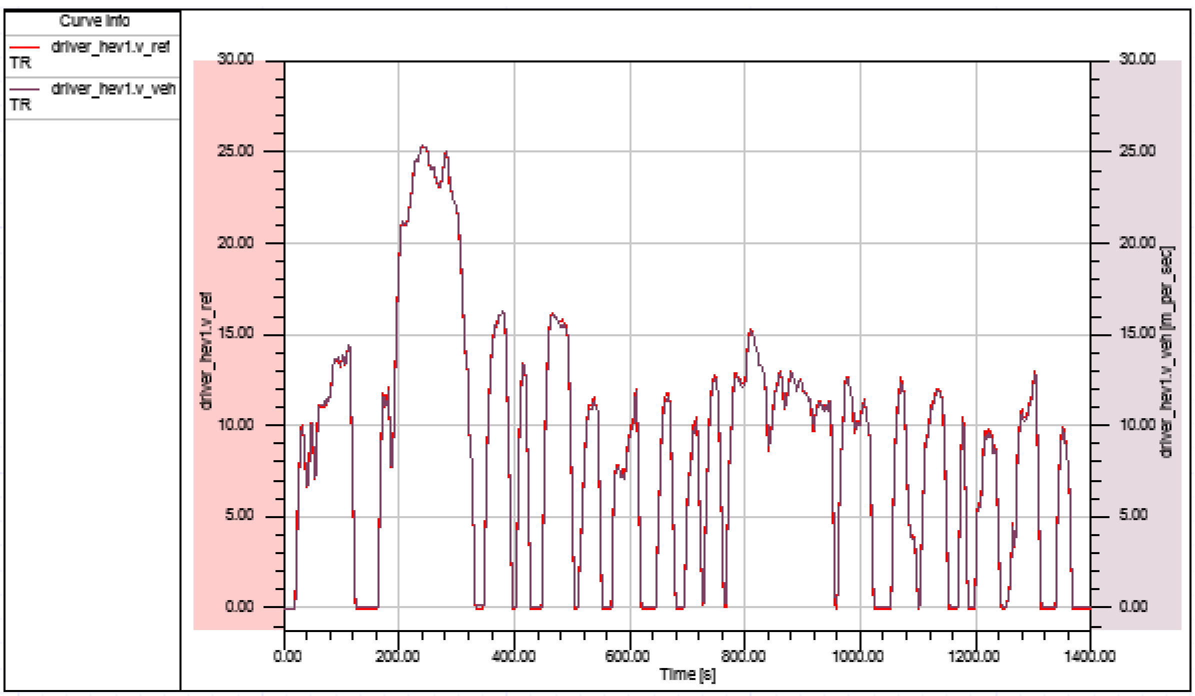

Figure 2: Given Reference Velocity vs. Model Calculated Vehicle Velocity of HEV Application

The fuel remaining in the fuel tank and the change in battery state of charge (SOC) during the vehicle driving process of the HEV application are shown in Figure 3.

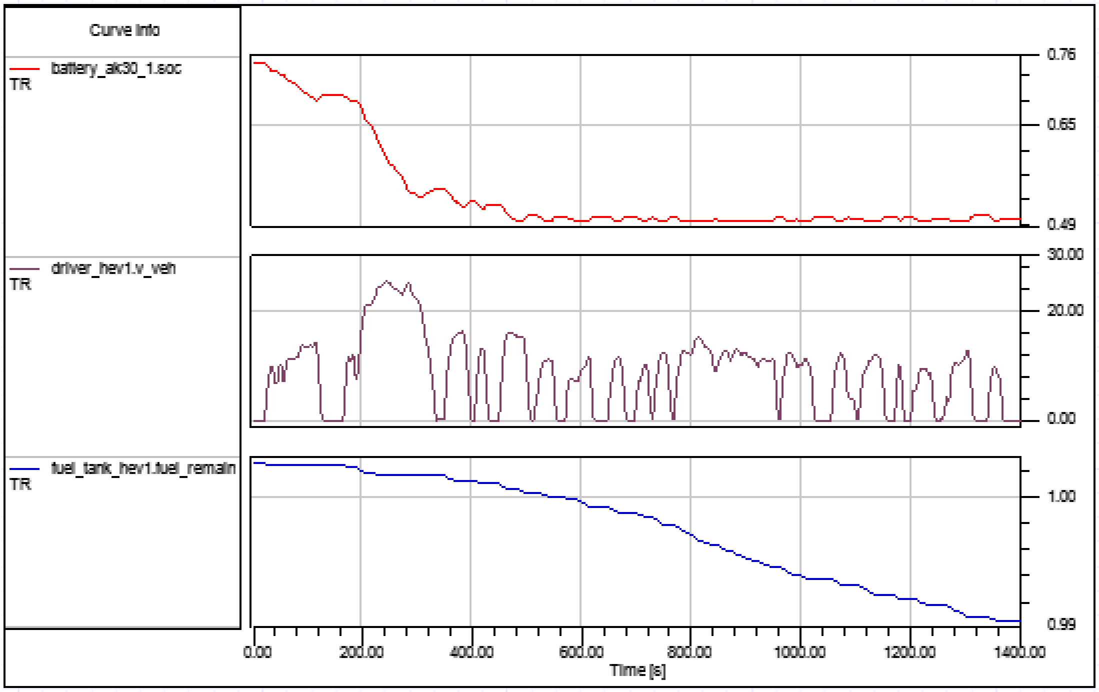

Figure 3: Model Calculated Vehicle Velocity vs. Fuel Remaining and Battery SOC of HEV Application

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Hybrid Electrical Vehicle (HEV) with Permanent Magnet Synchronous Motor (PMSM) Application

Description

The PMSM-based HEV application schematic is shown in Figure 1.

Its main 14 components are:

- driving cycle
- driver
- central controller (HEV)
- PMSM controller
- PMSM
- battery
- internal combustion engine (ICE)
- fuel tank
- clutch
- transmission
- mechanical coupling
- brake
- wheel
- vehicle body

The HEV with PMSM has a structure similar to the HEV. The main difference between them is the HEV with PMSM has a PMSM model and a PMSM controller instead of a DC motor and motor controller.

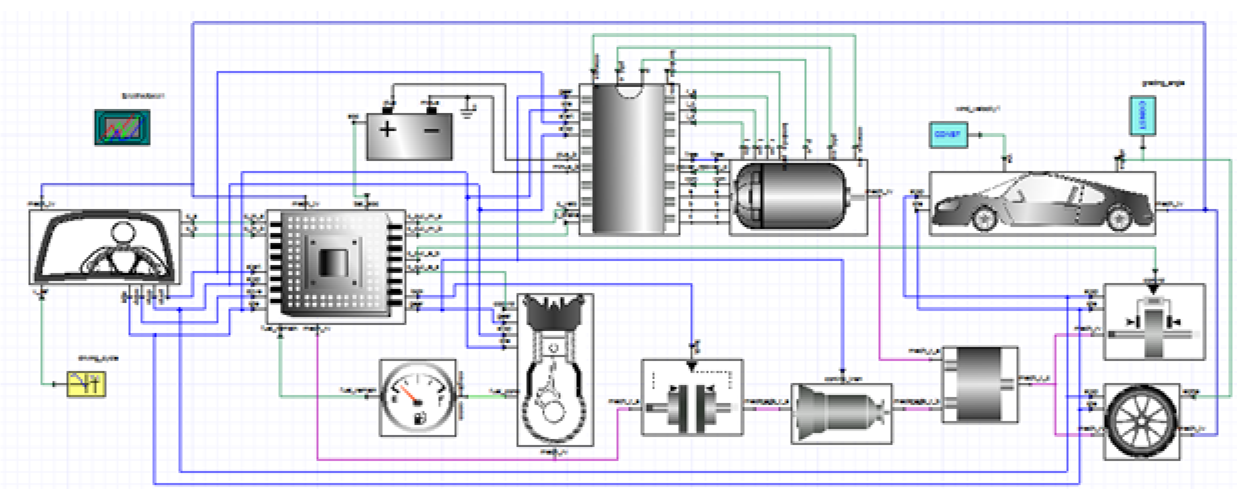

Figure 1: PMSM-based HEV Schematic

Figure 2 shows a comparison of the given reference velocity from the driving cycle and the model-calculated vehicle velocity of the HEV. The two velocities are very close to each other.

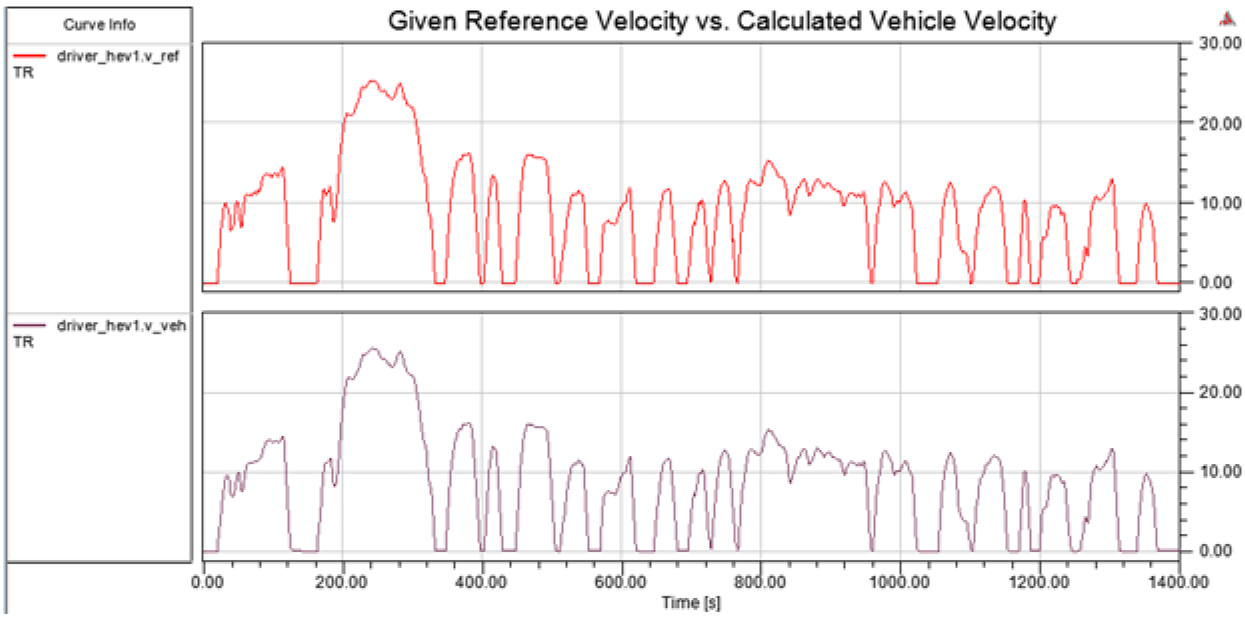

Figure 2: Given Reference Velocity vs. Calculated Vehicle Velocity of HEV Application

The fuel remaining in the fuel tank and the change in battery state of charge (SOC) during the vehicle driving process of the HEV application are shown in Figure 3.

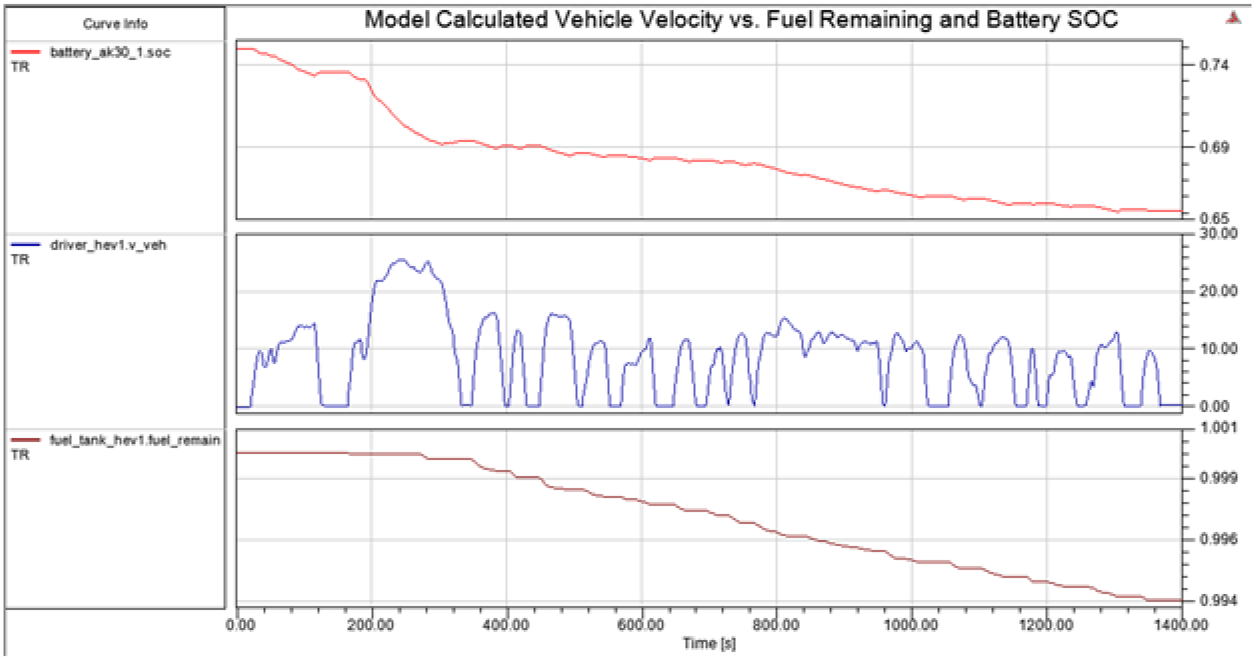

Figure 3: Model Calculated Vehicle Velocity vs. Fuel Remaining and Battery SOC of the PMSM-based HEV Application

The PMSM motor 3 phase voltages and currents are shown in figures 4 and 5.

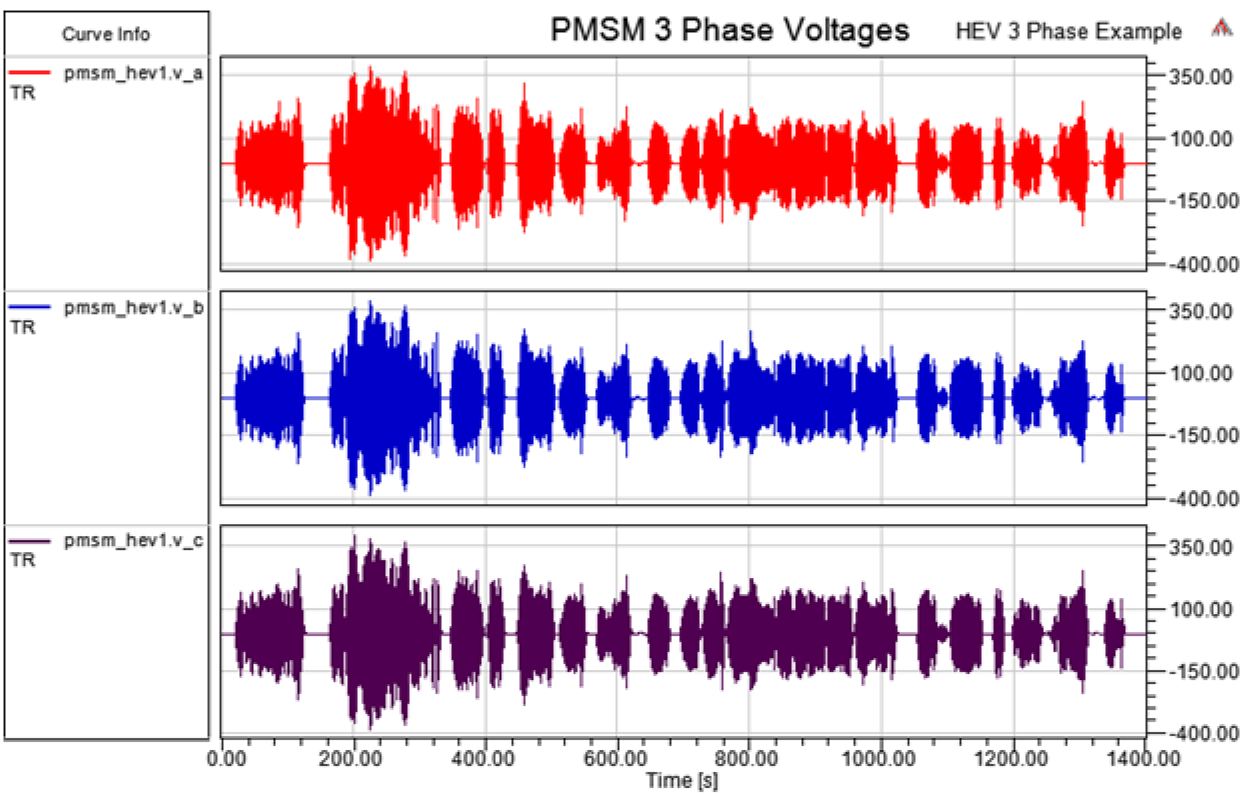

Figure 4: Permanent Magnet Synchronous Motor 3-Phase Voltages

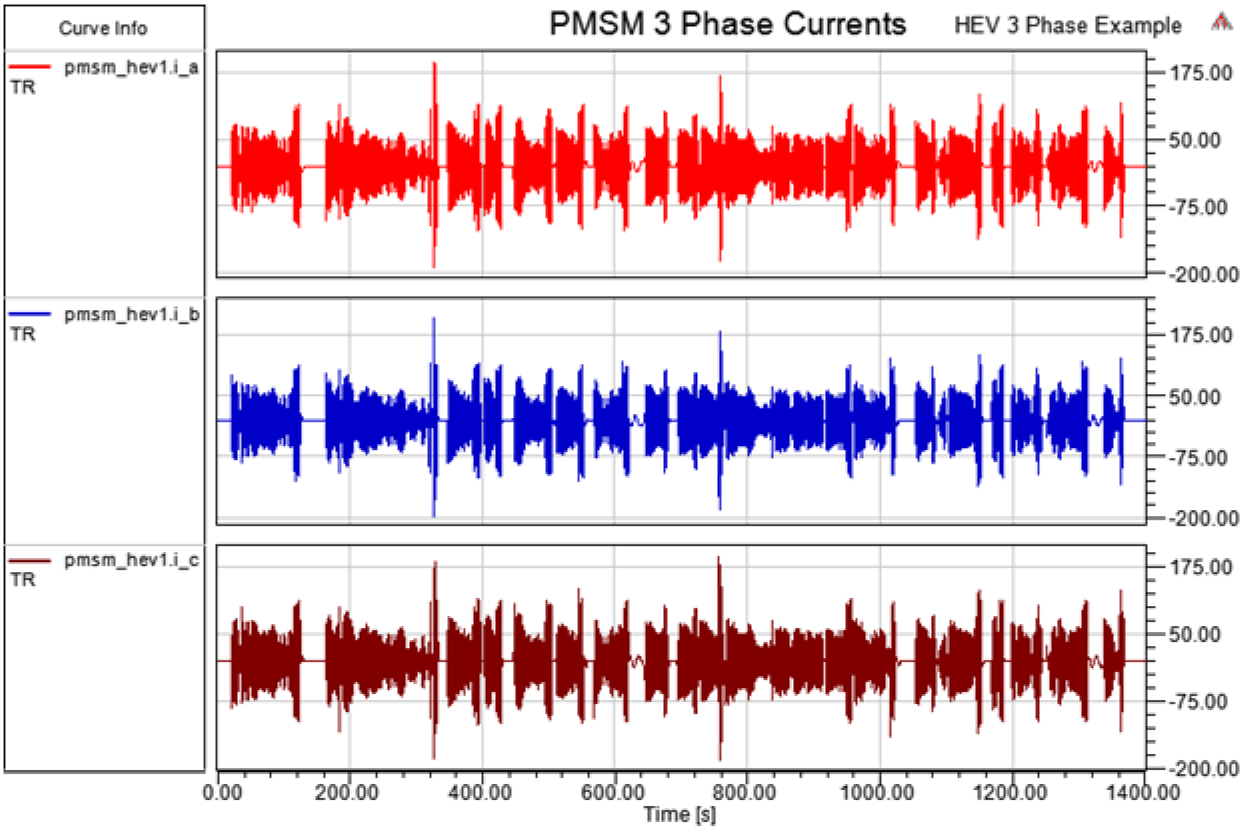

Figure 5: Permanent Magnet Synchronous Motor 3-Phase Currents

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