Mechanical Simulation
755 Phoenix Drive, Ann Arbor MI, 48108, USA
Phone: 734 668-2930 • Fax: 734 668-2877 • Email: info@carsim.com

Powertrain for Electric and Hybrid Electric Vehicles (BEV/HEV)

BikeSim, CarSim and TruckSim include parallel powertrain systems for battery electric vehicles (BEV) and hybrid electric vehicles (HEV). The electric and hybrid electric systems work with all the existing drive systems such as: FWD, RWD, and AWD in CarSim/TruckSim, or chain and shaft drive in BikeSim. The hybrid/electric system model also includes a power management control.

Installing the Electric or Hybrid Electric System

The default powertrain is a minimal powertrain provided as a backup for the closed-loop speed controller. To install and use a full powertrain, link to a Powertrain dataset from the **Vehicle: Assembly** library in BikeSim/CarSim or a **Vehicle: Lead Unit** library in TruckSim. From the Powertrain screen, select one of three options (below) from the ring control ① (Figure 1):

1. **Internal-combustion engine**: an engine, a hydraulic torque converter (or mechanical clutch) and a transmission are connected in series,
2. **Hybrid (engine + electric motor)**: various types of hybrid electric system involving an engine, a generator and a motor are configurable, such as series and parallel hybrid, etc.,
3. **Electric**: the power source is only an electric motor.

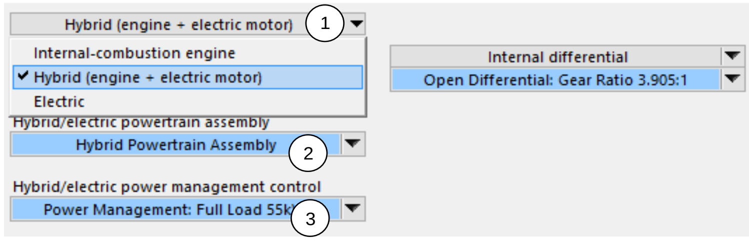


Figure 1. Select either internal-combustion, hybrid-electric or electric system (CarSim.)

Selecting either the menu item **Hybrid (engine + electric motor)** or **Electric** replaces two library links of IC (Internal-Combustion) components such as the torque converter and transmission screens with the links for **Powertrain: Hybrid/Electric System** 2 and **Hybrid/Electric Power Management control** 3 libraries, respectively.

The Powertrain: Hybrid/Electric System screen

Figure 2 shows the **Powertrain: Hybrid/Electric System** screen that assembles the hybrid/electric powertrain system components. The screen has a drop-down list 1 (Figure 3) for specifying the type of hybrid and electric powertrain. When **Electric** is selected in the list 1 (Figure 2), only the electric system parameters (six parameters of battery and five links for configurable functions) are shown.

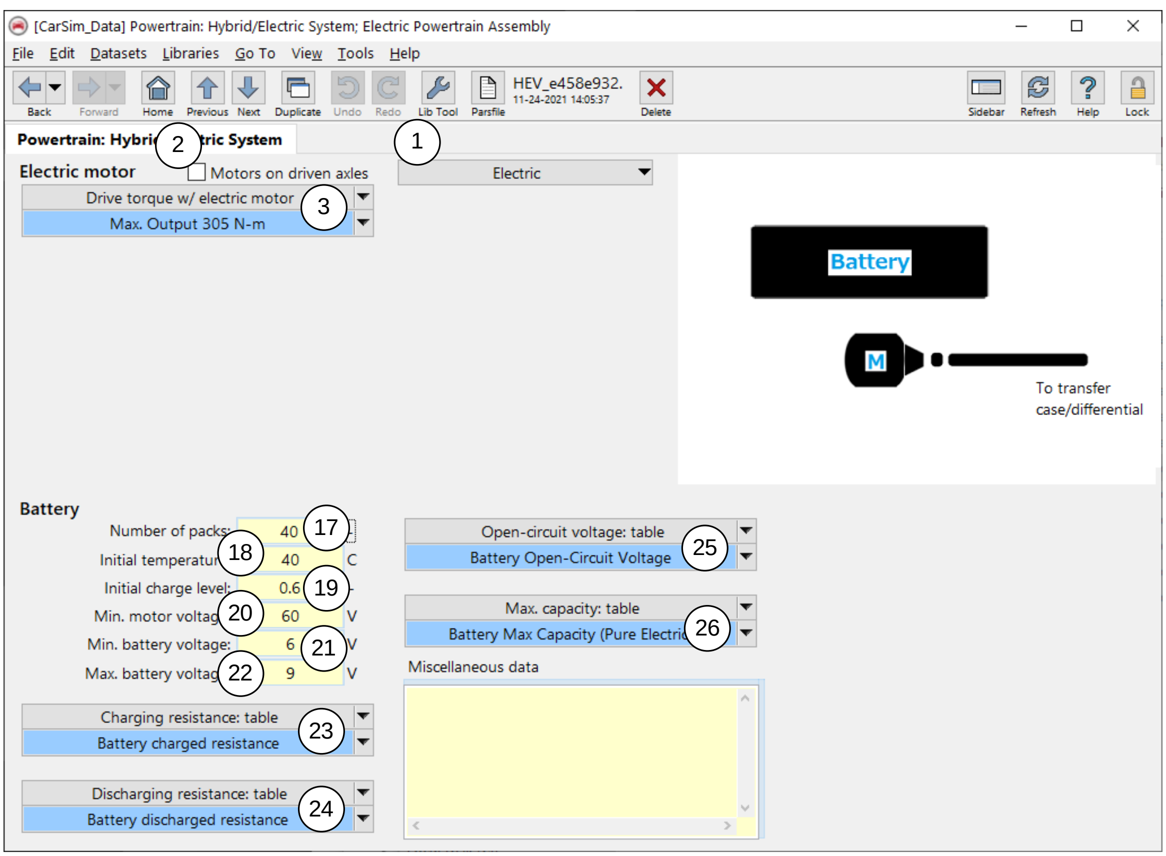
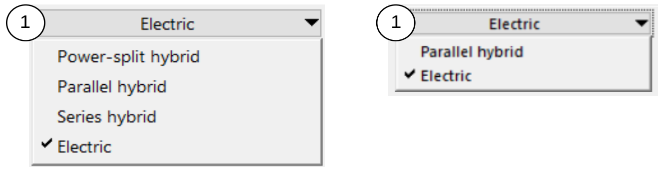


Figure 2. Powertrain: Hybrid/Electric System screen defining electric system.



a. CarSim/TruckSim b. BikeSim

Figure 3. Drop-down list to specify type of hybrid-electric powertrain.

There are four types of hybrid/electric powertrain system that may be specified with the install command `OPT_HEV` in CarSim and TruckSim (Figure 3a.) However, BikeSim supports parallel hybrid (`OPT_HEV` = 4) and Electric (`OPT_HEV` = 2) only (Figure 3b.)

1. **Power-split hybrid** (`OPT_HEV` = 1): an engine, a generator, and a motor are connected in parallel by a planetary gear.
2. **Parallel hybrid** (`OPT_HEV` = 4): an engine and a motor are in a parallel structure such that the engine and motor drive the wheels through a transmission when a clutch is engaged; the wheels are driven only by motor when the clutch is disconnected.
3. **Series hybrid** (`OPT_HEV` = 3, also known as "REEV: *Range-Extended EV*): an engine is directly connected with a generator that charges the electric battery; separate motor(s) drive the wheels.
4. **Electric** (`OPT_HEV` = 2): the power source is solely electric motor(s).

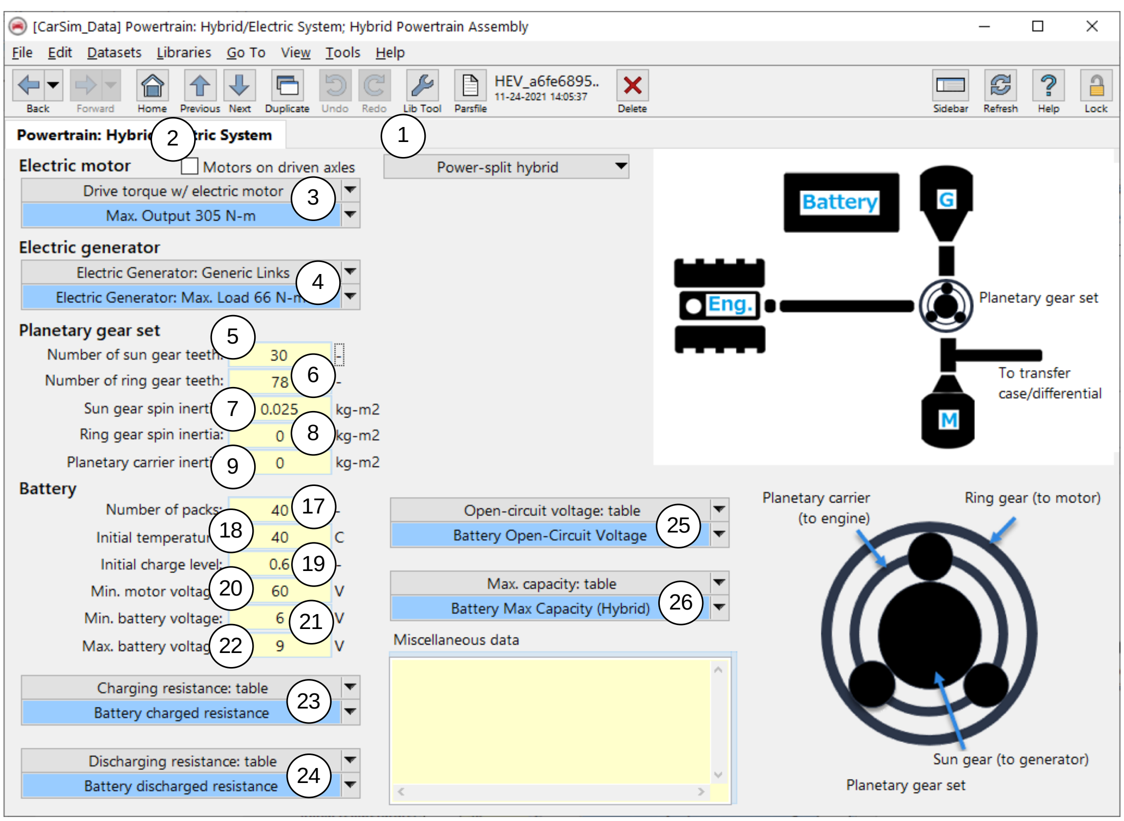


Figure 4. Powertrain: Hybrid/Electric System screen defining power-split hybrid system.

Select a hybrid system, for example, **power-split hybrid** in the list (1) to view additional controls for the generator and planetary gear associated with a power-split hybrid system (Figure 4).

The top-level powertrain settings are listed in the Echo file, such as the CarSim example shown in Figure 5.

```
!-----------------------------------------------------------------------------------
! POWERTRAIN
!-----------------------------------------------------------------------------------
! The powertrain model is specified with the following parameters along with up to
! 25 nonlinear Configurable Functions. Open-loop throttle can be specified with the
! function THROTTLE_ENGINE. Engine behavior is specified in part with the functions
! MENGINE and FUEL_RATE.

INSTALL_POWERTRAIN  2 ! Powertrain type: 0 -> Simple, 1 -> FWD, 2 -> RWD, 3 -> AWD,
                      ! 7 -> AVL Cruise [L]
! R_REAR_DRIVE_SC   1 ; - ! Drive torque ratio: [rear axle]/[total] [I]
OPT_HEV             2 ! Propulsion types: 0 -> internal-combustion engine, 1 ->
                      ! power-split hybrid electric, 2 -> electric, 3 ->
                      ! range-extended electric (series hybrid), 4 -> parallel
                      ! hybrid electric
OPT_MOTOR_ON_AXLE   0 ! Is electric motor placed on each drive axle?: 0 -> No, a
                      ! motor per vehicle; 1 -> Yes, a motor per drive axle
INSTALL_ELECTRIC_DRIVE_MOTORS  ! VS Command to install electric motors
```

```
! The Hybrid/Electric powertrain system parameters.

TC_PWR_HYBRID_AV  0.8 ; s ! Time constant for hybrid/electric available power

! The hybrid/electric powertrain battery parameters.

N_BATTERY          40 ; - ! Number of battery packs [I]
T_BATTERY_INIT     40 ; C ! Initial battery temperature [I]
BATTERY_CHARGE_INIT 0.6 ; - ! Initial battery charged level [I]
V_MOTOR_MIN        60 ; V ! Minimum voltage for electric motor [I]
V_BATTERY_MIN       6 ; V ! Minimum voltage per battery pack [I]
V_BATTERY_MAX       9 ; V ! Maximum voltage per battery pack [I]

! The hybrid/electric power management control parameters.

PWR_EV_MODE        25 ; kW ! Maximum power allowance operated with EV mode [I]
PWR_HEV_DRV_MAX    55 ; kW ! Maximum power available with HEV system (used by speed
                      ! control only) [I]
KPW_PBK_HEV        16 ; kW/MPa ! Brake power demand per master cylinder control
                      ! pressure [I]
OPT_REGEN_OFF_THRT  0 ; - ! Charge battery when vehicle is coasting with off
                      ! throttle and off brakeing: 0 -> no, 1 -> yes [I]
CF_HEV_PBK       0.08 ; - ! [D] Control shape factor for regenerative motor power
                      ! around zero speed [I]
REGEN_BRK_OFF     0.8 ; - ! Battery charged level to turn off regenerative brake [I]

! The hybrid/electric powertrain motor parameters.

IMOTOR         0.0226 ; kg-m2 ! Spin inertia of electric motor [I]
TC_MOTOR         0.05 ; s ! Time constant for electric motor torque
```

Figure 5. Powertrain section of a CarSim Echo file for vehicle with electric powertrain.

The first item is a command `INSTALL_POWERTRAIN` which installs a powertrain followed by a parameter that specifies type, ranging from 0 (simple drive provided by the built-in speed controller), through various numbers of drive axles (2 in CarSim, and up to 5 in TruckSim), and including the external powertrain model from AVL.

`OPT_HEV` is another combination command and parameter: this is corresponding to the drop-down list (1) (Figure 3,) parameter value specifies as 0: IC Engine, 1: power-split hybrid, 2: electric, 3: series hybrid and 4: parallel hybrid.

Also, a single electric motor per powertrain or multiple electric motors for all driven axles are installed by a command `INSTALL_ELECTRIC_DRIVE_MOTORS` with specifying option parameter `OPT_MOTOR_ON_AXLE`.

All other parameters are listed in the echo files for electric system (Figure 5) and power-split hybrid system (Figure 6.)

```
! The hybrid powertrain planetary gear parameters.

N_TH_SUN           30 ; - ! Number of teeth in sun gear [I]
N_TH_RING          78 ; - ! Number of teeth in ring gear [I]
IPLNT_SUN           0 ; kg-m2 ! Spin inertia of planetary sun gear [I]
IPLNT_RING          0 ; kg-m2 ! Spin inertia of planetary ring gear [I]
IPLNT_CR            0 ; kg-m2 ! Spin inertia of planetary carrier gear [I]

! The hybrid powertrain generator parameters.

IGNRTR         0.0226 ; kg-m2 ! Spin inertia of electric generator [I]
TC_GNRTR         0.05 ; s ! Time constant for electric generator torque

! The hybrid/electric power management control parameters.

K_BATTERY_CHARGE  150 ; kW ! Battery charging control gain [I]
PWR_EV_MODE        25 ; kW ! Maximum power allowance operated with EV mode [I]
PWR_ENG_MODE       50 ; kW ! Maximum power allowance operated with engine mode [I]
PWR_HEV_DRV_MAX    55 ; kW ! Maximum power available with HEV system (used by speed
                      ! control only) [I]
KPW_PBK_HEV        16 ; kW/MPa ! Brake power demand per master cylinder control
                      ! pressure [I]
CF_HEV_PBK       0.08 ; - ! [D] Control shape factor for regenerative motor power
                      ! around zero speed [I]
VLOW_ENG_MODE      45 ; km/h ! Minimum vehicle speed operated with engine mode [I]
VLOW_BATTERY_CHARGE 15 ; km/h ! Minimum vehicle speed to charge battery [I]
AV_GNRTR_LIMIT   5850 ; rpm ! Generator speed limit (absolute value applied for both
                      ! positive and negative) [I]
GNR_CONTROL_KP 0.0157 ; N-m-s/deg ! Generator speed controller: proportional gain
                      ! [I]
GNR_CONTROL_KI 8.73e-05 ; N-m/deg ! Generator speed controller: integral gain [I]
BATTERY_CHARGE_LOW 0.55 ; - ! Lower boundary of battery charged level [I]
BATTERY_CHARGE_TARG 0.6 ; - ! Target battery charged level [I]
REGEN_BRK_OFF     0.8 ; - ! Battery charged level to turn off regenerative brake [I]
```

Figure 6. Additional parameters for the built-in hybrid-electric powertrain system (power-split).

Table 1 summarizes ten configurable table functions used by hybrid and/or electric system.

Table 1. Summary of BEV/HEV powertrain system configurable functions.

Root Keyword	**Description**	**BEV and/or HEV**
MMOTOR_MAX	Maximum motor torque vs. motor speed	BEV and HEV
R_EFF_MOTOR	Motor efficiency vs. motor speed	BEV and HEV
MGNRTR_MAX	Maximum generator load vs. motor speed	HEV only
R_EFF_GNRTR	Generator efficiency vs. motor speed	HEV only
R_CHRG_BATTERY	Battery charging resistance vs. state of battery charged	BEV and HEV
R_DIS_BATTERY	Battery discharging resistance vs. state of battery charged	BEV and HEV
VOC_BATTERY	Battery open-circuit voltage vs. state of battery charged	BEV and HEV
CAP_BATTERY_MAC	Battery capacity vs. temperature	BEV and HEV
PWR_DRV_THROTTLE	Driver demand power vs. throttle position	BEV and HEV
VENGINE_OPTIMAL	Optimal engine speed vs. power demand	HEV only

Note: Selecting the menu item **Electric** does not install the generator and planetary gear, which are only used by the hybrid system.

Electric Motor and Generator

The torque outputs of the motor and generator are based on those torque command inputs. The torque output (T) is a first order lag element of the torque command input (T_{cmd}), which is limited by a lookup table (f_T) of the maximum torque as a function of rotational speed (ω) such as:

$$\dot{T} = \frac{\mathrm{sign}[\min\{f_T(\omega), |T_{cmd}|\}, T_{cmd}] - T}{t_C} \tag{1}$$

where t_C is the time constant. The efficiency is calculated by a lookup table (f_E) as a function of output torque and rotational speed:

$$E = f_E(T, \omega) \tag{2}$$

The power (P) is calculated by the output torque (T), rotational speed (ω) and efficiency (E) which is either divided or multiplied depending on the positive (discharging) or negative power (charging) such as:

$$P = T\frac{\omega}{E} \quad (P \geq 0, \text{discharge})$$
$$P = T \cdot \omega \cdot E \quad (P < 0, \text{charge}) \tag{3}$$

User settings

2 **Motor on driven axles** check box (keyword = `OPT_MOTOR_ON_AXLE`). If this checkbox is checked, a motor is installed on each driven axle and the electric motor link is hidden from this screen (Figure 7). In this case, the electric motor library can be linked from the differential screen for each driven axle.

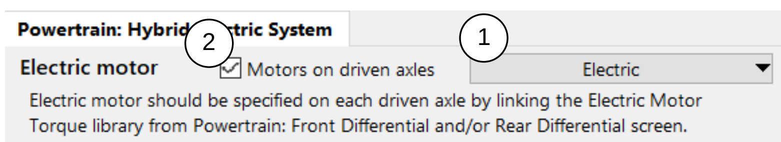


Figure 7. Option for motors on a driven axle.

If the motors are located on the front and rear drive axles, the motor torque command (T_{motor_cmd}) calculated by the motor controller (equation 36) is distributed on each of driven axles through the differential indexed parameters (`R_REAR_MOTOR_BIAS(IDIFF)`) which represents such an eAWD.

> **Note** Checkbox 2 is applicable and visible in CarSim and TruckSim only.

3 Link to a **Powertrain: Electric Motor Torque** dataset. An electric motor is characterized by two configurable functions: motor maximum torque and efficiency, and two parameters: motor spin inertia (keyword = `I_MOTOR`) and time constant for the first order lag (keyword = `TC_MOTOR`). Details of the settings are provided later (page 13).

4. Link to a generic group screen to configure an electric generator by two configurable functions for the generator maximum load and efficiency; and two parameters: generator spin inertia (keyword = `IGNRTR`) and time constant for the first order lag (keyword = `TC_GNRTR`).

> **Note:** An electric powertrain system (`OPT_HEV = 2`) does not calculate the torque, efficiency, and power for the generator.

Planetary Gear Set (Power-split Hybrid Only)

When a power-split hybrid is employed (`OPT_HEV = 1`), the output torque from the hybrid powertrain system (T_{hev_out}) that is the input torque to either the transfer case or axle differential is calculated by the three output torques from the electric motor (T_{motor}), electric generator (T_{gnrtr}) and internal combustion engine (T_e):

$$T_{hev\_out} = T_{motor} + T_e \frac{N_r}{N_r+N_s} + \frac{I_{ec}}{I_{gs}} \cdot \frac{{N_s}^2 T_{motor} - N_s N_r T_{gnrtr}}{(N_r+N_s)^2} \tag{4}$$

where N_s and N_r are the numbers of teeth on the sun and ring gear, respectively. I_{ec} is the sum of spin inertia of the engine crankshaft and planetary carrier, while I_{gs} is the sum of spin inertia of the generator and sun gear.

The total spin inertia of the HEV system (I_{hev}) is transferred to drive wheels in the same manner as the conventional powertrain model transferring the transmission inertia to the wheels (refer to I_{trans} on the separate Help document *Powertrain System*). I_{hev} on the HEV system is:

$$I_{hev} = I_{mr} + \frac{I_{ec}}{I_{gs}} \cdot \frac{{N_s}^2 {I_{mr}}^* + {N_r}^2 I_{gs}}{(N_r+N_s)^2} \tag{5}$$

where I_{mr} is the sum of spin inertia of the electric motor and ring gear and I_{mr}^* is the sum of spin inertia from the electric motor all the way through the wheels (refer to $I_{driveline}$ for the conventional powertrain on the separate Help document *Powertrain System*).

The generator (sun gear) angular acceleration is:

$$\dot{\omega}_{gnrtr} = \frac{T_{gnrtr} + T_e \frac{N_s}{N_r+N_s} + \frac{I_{ec}}{{I_{mr}}^*} \cdot \frac{{N_r}^2 T_{gnrtr} - N_s N_r T_{motor}}{(N_r+N_s)^2}}{I_{gs} + \frac{I_{ec}}{{I_{mr}}^*} \cdot \frac{{N_s}^2 {I_{mr}}^* + {N_r}^2 I_{gs}}{(N_r+N_s)^2}} \tag{6}$$

The generator angular acceleration is numerically integrated to have the generator speed (ω_{gnrtr}). The motor speed (ω_{motor}) is derived from the drive wheel speeds back way propagating through the differential/transfer case (refer to ω_g on the separate Help document *Powertrain System*). The engine speed (equal to the planetary carrier speed) is derived by the motor and generator speeds:

$$\omega_e = \frac{N_r \cdot \omega_{motor} + N_s \cdot \omega_{gnrtr}}{N_r+N_s} \tag{7}$$

Note: If the motors are located on the drive axles (`OPT_MOTOR_ON_AXLE=1`; 2 is checked), the motor torque and inertia in equations 4-6 are treated as zero and the term of the motor speed (ω_{motor}) is replaced by the transmission output angular speed (ω_g) in equation 7.

User settings

5 Number of sun gear teeth (keyword = `N_TH_SUN`).

6 Number of ring gear teeth (keyword = `N_TH_RING`).

7 Planetary sun gear spin inertia (keyword = `IPLNT_SUN`). The sun gear is connected to the generator and this spin inertia is added on the generator.

8 Planetary ring gear spin inertia (keyword = `IPLNT_RING`). The ring gear is connected to the motor and this spin inertia is added on the motor.

9 Planetary carrier spin inertia (keyword = `IPLNT_CR`). The planetary carrier is connected to the engine and this spin inertia is added on the engine.

Clutch and Transmission (Parallel Hybrid Only)

When a parallel hybrid is employed (`OPT_HEV` = 4), the powertrain involves a clutch, a transmission, and a pre- or post-transmission electric motor (Figure 8).

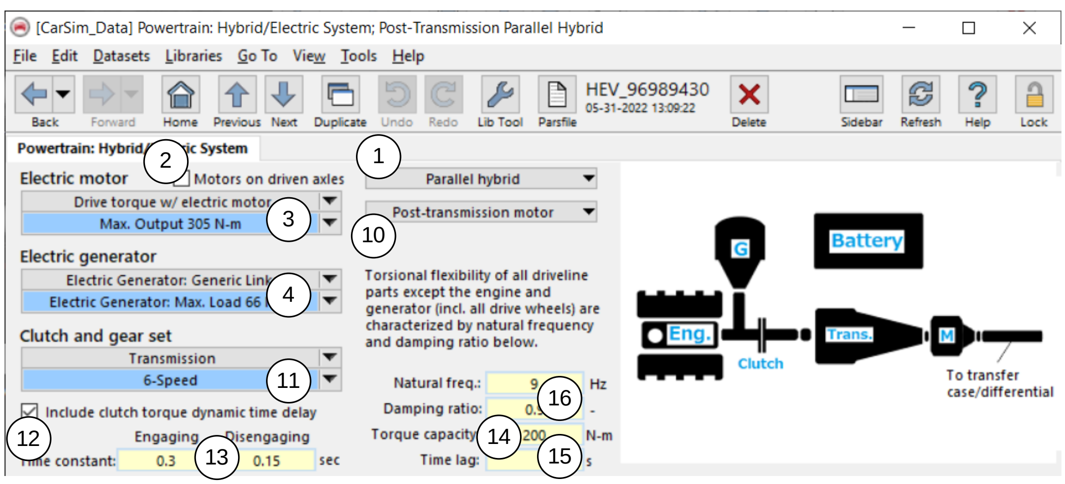


Figure 8. Powertrain: Hybrid/Electric System screen defining parallel hybrid system

There is an additional drop-down list 10 to specify the location of the electric motor either before the transmission (right after the engine and clutch) or after the transmission (Figure 9).

Note When the checkbox for motors on drive axles 2 is checked, the drop-down list 10 is hidden and the motor location is treated as after the transmission.

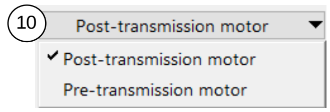


Figure 9. Drop-down list to specify the electric motor location of parallel hybrid.

Regardless of the electric motor location, when the clutch is completely disengaged, the wheels are driven only by the electric motor. When the clutch is fully engaged (locked) or slipping with the clutch load, the engine torque is transmitted to wheels through the transmission. Therefore, by modulating the clutch, it can control three different driving operations such as: motor only, engine only, and motor + engine.

The transmission has a torsional flexibility and the output torque from the hybrid powertrain system (T_{hev_out}) is given by the torsional spring-damper, such as:

$$T_{hev\_out} = K_{driveline} \times (\varphi_{grout} - \varphi_{hev\_out}) + D_{driveline} \times (\omega_{grout} - \omega_{hev\_out}) + T_{motor\_post\_trans}, \qquad (8)$$

where the torsional stiffness ($K_{driveline}$), damping coefficient ($D_{driveline}$) of the entire driveline, and post-transmission electric motor torque ($T_{motor\_post\_trans}$.)

When the transmission is geared, the transmission gear ratio (N_{trans}) is associated with either the selected gear number or continuously variable. The output torque of the transmission gearbox (T_{grout}) is given by the clutch output torque (T_{cl}), pre-transmission electric motor torque ($T_{motor\_pre\_trans}$,) gear ratio and efficiency depending on whether the engine drives the wheels or the wheels drive the engine, such as:

$$T_{grout} = N_{trans} \times (T_{cl} + T_{motor\_pre\_trans}) \times E_{trans} \quad (T_{tcout}{}^{*} \geq 0) \quad \text{or}$$
$$T_{grout} = N_{trans} \times (T_{cl} + T_{motor\_pre\_trans}) / E_{trans} \quad (T_{tcout}{}^{*} < 0) \qquad (9)$$

where E_{trans} is the efficiency (multiplying) when the engine drives the wheels. On the other hand, E_{trans_rev} is the efficiency (dividing) when the wheels drive the engine. Those two efficiencies are switched depending on the direction of the torque through the transmission.

The gearbox output speed is given by:

If clutch is slipping

$$\dot{\omega}_{grout} = \alpha_{grout} = \frac{T_{grout} - T_{hev\_out}}{I_{motor\_pre\_trans} \cdot N_{trans}{}^{2} + 0.5 I_{trans}}$$

else (clutch is locked)

$$\dot{\omega}_{grout} = \alpha_{grout} = \frac{T_{grout} - T_{hev\_out}}{(I_e + I_{motor\_pre\_trans}) \cdot N_{trans}{}^{2} + 0.5 I_{trans}} \qquad (10)$$

Note Either $T_{motor\_post\_trans}$ in equation 8 or $T_{motor\_pre\_trans}$ in equation 9 will be zero, depending on the setting on the list 10. For example, if the post-transmission motor is specified, $T_{motor\_pre\_trans}$ is zero.

> $I_{motor\_pre\_trans}$ in equation 10 is zero if the post-transmission motor is specified. Instead, the inertia of the post-transmission motor is added on driving wheels in the same treatment as the differential inertia.

In case of the locked clutch, the engine, generator, and transmission gearbox are all treated as one unit such as:

$$T_{cl} = T_e + T_{gnrtr}$$
$$\omega_e = \omega_{gnrtr} = N_{trans} \times \omega_{grout} \tag{11}$$

On the other hand, in case the clutch is not locked (either fully disengaged or slipping), the clutch torque is the torque capacity specified by the yellow field ⑭ and speed difference between the engine speed and transmission input shaft speed ($d\omega_{clutch}$) such as:

$$T_{cl} = \mathrm{sign}\left(T_{clutch\_cap}, d\omega_{clutch}\right) \tag{12}$$

where `sign` is the sign function that the sign of the first term (T_{clutch_cap}) depends on the sign of the second term ($d\omega_{clutch}$).

When the clutch is not locked, the engine and generator speed is given by:

$$\omega_e = \omega_{gnrtr}$$
$$\dot{\omega}_e = \dot{\omega}_{gnrtr} = \frac{T_e + T_{gnrtr} - T_{cl}}{I_e + I_{gnrtr}} \tag{13}$$

User settings

⑩ Drop-down list to specify the location of the electric motor (keyword = `OPT_PRE_TRANS_PARALLEL_HYBRID`).

⑪ Link to **Powertrain: Transmission** dataset.

⑫ Checkbox for using a 1st order time delay of the clutch torque capacity (keyword = `OPT_HEV_CLUTCH_DELAY`). When checked, extra data fields ⑬ are shown that specify the time constants. If not checked, the clutch torque responds instantly without delay.

⑬ Dynamic time constants for engaging and disengaging the clutch (keyword = `TC_HEV_CLUTCH_ENGAGE` and `TC_HEV_CLUTCH_DISENGAGE`, respectively).

⑭ Maximum torque capacity of the lockup clutch (keywords = `M_HEV_CLUTCH_CAP`).

⑮ Time lag between the time to switch to engine mode and actual clutch engagement is initiated (keywords = `T_HEV_CLUTCH_LAG`).

⑯ Natural frequency and damping ratio of driveline (CarSim/TruckSim only) (keyword = `DRIVELINE_FREQ` and `DRIVELINE_ZETA`).

Pure Electric and Range-extended Electric (Series Hybrid)

When a pure electric (`OPT_HEV` = 2) or series hybrid (also known as range-extended electric, `OPT_HEV` = 3) is employed, the output torque from the hybrid/electric powertrain system (T_{hev_out}) is simply the electric motor torque (T_{motor}):

$$T_{hev\_out} = T_{motor} \tag{14}$$

When the series hybrid (`OPT_HEV` = 3) is employed, the engine / generator speed is given by:

$$\omega_e = \omega_{gnrtr}$$

$$\dot{\omega}_e = \dot{\omega}_{gnrtr} = \frac{T_e + T_{gnrtr}}{I_e + I_{gnrtr}} \tag{15}$$

Battery and Electric Circuit

The battery model calculates the voltage, current and resistance based on the power required by the motor and generator. The battery required power (P_{bttry}) is:

$$P_{bttry} = P_{motor} + P_{gnrtr} \tag{16}$$

Note: P_{gnrtr} is 0 with the electric powertrain system (`OPT_HEV = 2`). If motors are on two or more driven axles (`OPT_MOTOR_ON_AXLE=1`; 2 is checked), P_{motor} is the sum of power from all electric motors.

The open-circuit voltage of battery is calculated by a function (f_{voc}) of temperature (temp) and battery state of charged (soc):

$$V_{oc} = N_{bttry} \cdot f_{VOC}(temp, soc) \tag{17}$$

The resistance (R) is calculated by either a function, f_{R_dis} or f_{R_chr}, depending on the positive (discharging) or negative (charging) battery required power such as:

$$R = N_{bttry} \cdot f_{R\_dis}(temp, soc) \quad (P_{bttry} \geq 0,\ discharge)$$

$$R = N_{bttry} \cdot f_{R\_chr}(temp, soc) \quad (P_{bttry} < 0,\ charge) \tag{18}$$

The battery power is limited for both discharging and charging. The battery discharged power limit is defined by:

$$V_{limit} = \max(V_{OC}/2, V_{m\_min}, V_{bttry\_min} * N_{bttry}) \tag{19}$$

$$P_{btr\_Ds} = \frac{(V_{OC} - V_{limit}) \cdot V_{limit}}{R} - 0.1$$

where V_{m_min} is minimum motor voltage and V_{bttry_min} is minimum battery voltage. The value of 0.1 is subtracted by modeler's experience.

The battery charged power limit is defined by:

$$P_{btr\_Ch} = \frac{(V_{OC} - V_{bttry\_max} \cdot N_{bttry}) \cdot V_{bttry\_max} \cdot N_{bttry}}{R} \tag{20}$$

The battery power is limited by the discharged limit as:

$$P_{limit} = \min(P_{bttry}, P_{btr\_Ds}) \tag{21}$$

The battery current is calculated by either

$$A_{bttry} = \frac{V_{OC} - \sqrt{V_{OC}^2 - 4P_{limit} \cdot R}}{2R}$$

or

$$A_{bttry} = \frac{V_{OC} - V_{bttry\_max} \cdot N_{bttry}}{R} \tag{22}$$

whichever gives the larger value. The battery output voltage is:

$$V_{bttry} = V_{OC} - A_{bttry} \cdot R \tag{23}$$

State of charge algorithm

The discharged capacity of the battery is derived by integration of the current:

$$C_{btr\_Ds} = \int A_{bttry} dt / 3600 \tag{24}$$

where the unit of discharged capacity is converted to [A-h] dividing by 3600. The battery state of charge (soc) is calculated by using the maximum capacity (C_{max}), which is a function of temperature:

$$C_{max} = f_{bttry\_cap}(temp)$$

$$soc = (C_{max} - C_{brt_{Ds}})/C_{max} \tag{25}$$

The battery efficiency is:

$$E_{bttry} = V_{bttry}/V_{OC} \tag{26}$$

User settings

⑰ Number of the battery packs (keyword = `N_BATTERY`).

⑱ Initial battery temperature (keyword = `T_BATTERY_INIT`). The units are centigrade. Despite the number of battery packs, the battery temperature is treated as uniform.

⑲ Initial charged level of battery (keyword = `BATTERY_CHARGE_INIT`).

⑳ Minimum motor voltage (keyword = `V_MOTOR_MIN`).

㉑ Minimum battery voltage (keyword = `V_BATTERY_MIN`).

㉒ Maximum battery voltage (keyword = `V_BATTERY_MAX`).

㉓ Link to the configurable function of battery charging resistance.

㉔ Link to the configurable function of battery discharging resistance.

25 Link to the configurable function of battery open-circuit voltage.

26 Link to the configurable function of battery maximum capacity.

Powertrain: Electric Motor Torque Screen

The way to calculate the electric motor output torque is described in the section: **Electric Motor and Generator** (page 6.) The motor output torque is limited by a lookup table (root keyword = MMOTOR_MAX) which is specified on the **Powertrain: Electric Motor Torque** screen as shown in Figure 10. The screen is accessible from the **Powertrain: Hybrid/Electric System screen** (Figure 2) or differential screen if the option for motors on drive axles (2 in Figure 2) is check in CarSim and TruckSim.

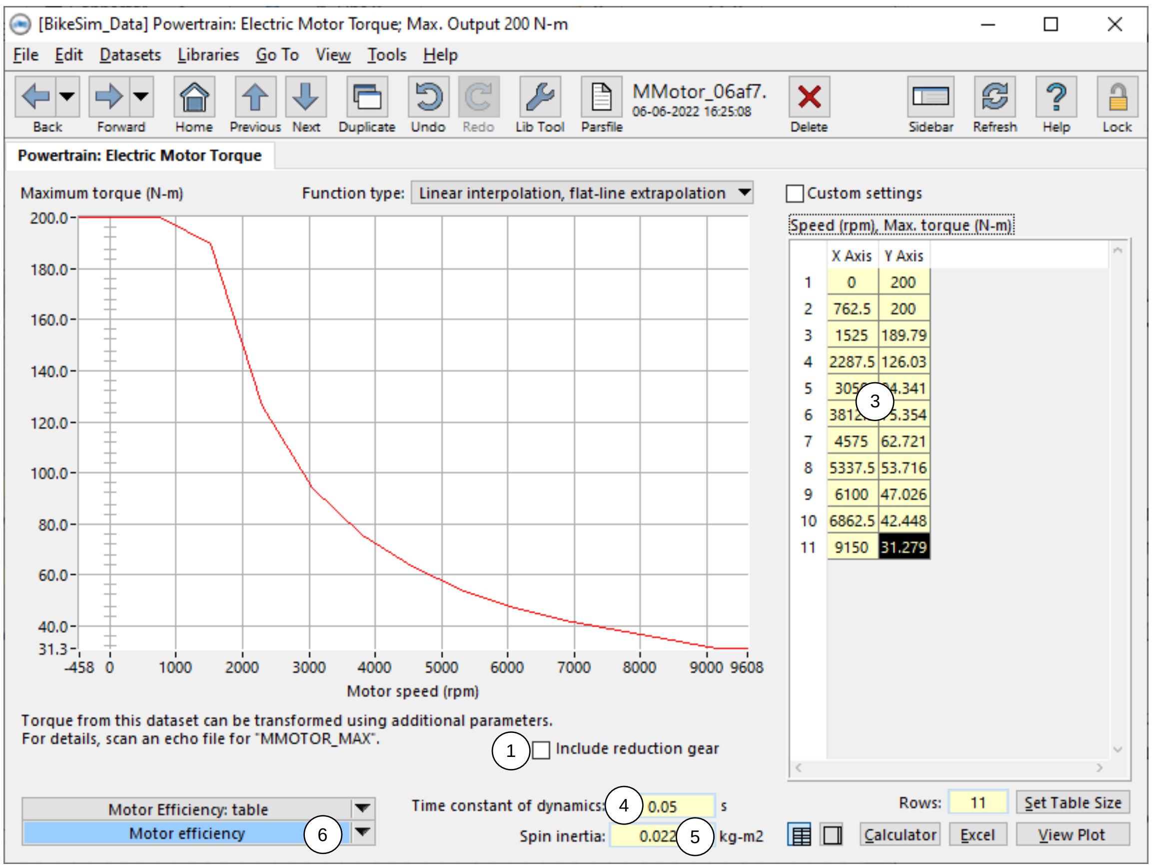


Figure 10. The Powertrain: Electric Motor Torque screen.

Information for the Vehicle Model

The vehicle model will use a few parameters and the tabular data from the screen, described below.

1 Optional checkbox to include reduction gear. When this checkbox is unchecked as shown in Figure 10, the motor speed and motor torque output are applied in the vehicle model as specified by the tabular data 3 without any modification.

On the other hand, when this checkbox is checked, an additional parameter field 2 appears to specify the reduction gear ratio (Figure 11.)

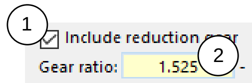


Figure 11. Specifying the reduction gear ratio of the electric motor

If the reduction gear is involved, motor speed and output toque of the tabular data 3 and motor spin inertia 5 are scaled by the gear ratio 2.

2 Motor reduction gear ratio (screen keyword = `*GEAR`). This is the reduction gear ratio of the electric motor. The reduction gear location is right after the electric rotor shaft. If this gear ratio is smaller than 1.0 (e.g., 0.8,) it will become an accelerating gear.

3 Table of motor speed (rpm) and maximum torque (N-m) (root keyword = `MMOTOR_MAX`). This table includes the options for viewing and editing tables that are described in the *VehicleSim Browser Reference Manual*. No matter of the reduction gear is involved or not, the motor speed and torque specified by this table are at the electric rotor shaft location. When the reduction gear is involved (1 is checked,) the motor speed and output torque are scaled for this configurable function, such as:

`SPIN_SCALE_M_MOTOR_MAX` = 1/(gear ratio)

`MMOTOR_MAX_GAIN` = gear ratio

4 Time constants used in the equation for motor output torque (equation 1, keyword = `TC_MOTOR`).

5 Electric motor rotational inertia at rotor (keyword = `I_MOTOR`). This parameter includes the inertia properties of all parts that spin with the electric rotor shaft. When the reduction gear is involved (1 is checked,) this inertia is modified with multiplying by power of the reduction gear ratio.

6 Link to table of motor efficiency (root keyword = `R_EFF_MOTOR`).

Powertrain: Hybrid/Electric Power Management Control

The **Powertrain: Hybrid/Electric Power Management Control** screen showing only the parameters for the electric powertrain system (5 parameters and 1 link for a configurable function) is shown in Figure 12. Un-check the box 1, to view additional controls for the hybrid powertrain system as shown in Figure 13.

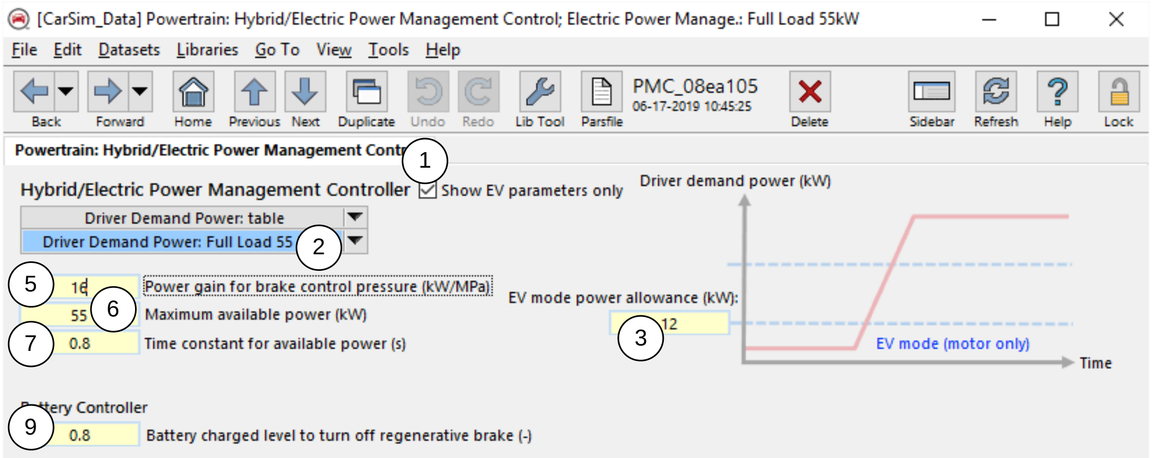


Figure 12. Powertrain: Hybrid/Electric Power Management Control screen for BEV

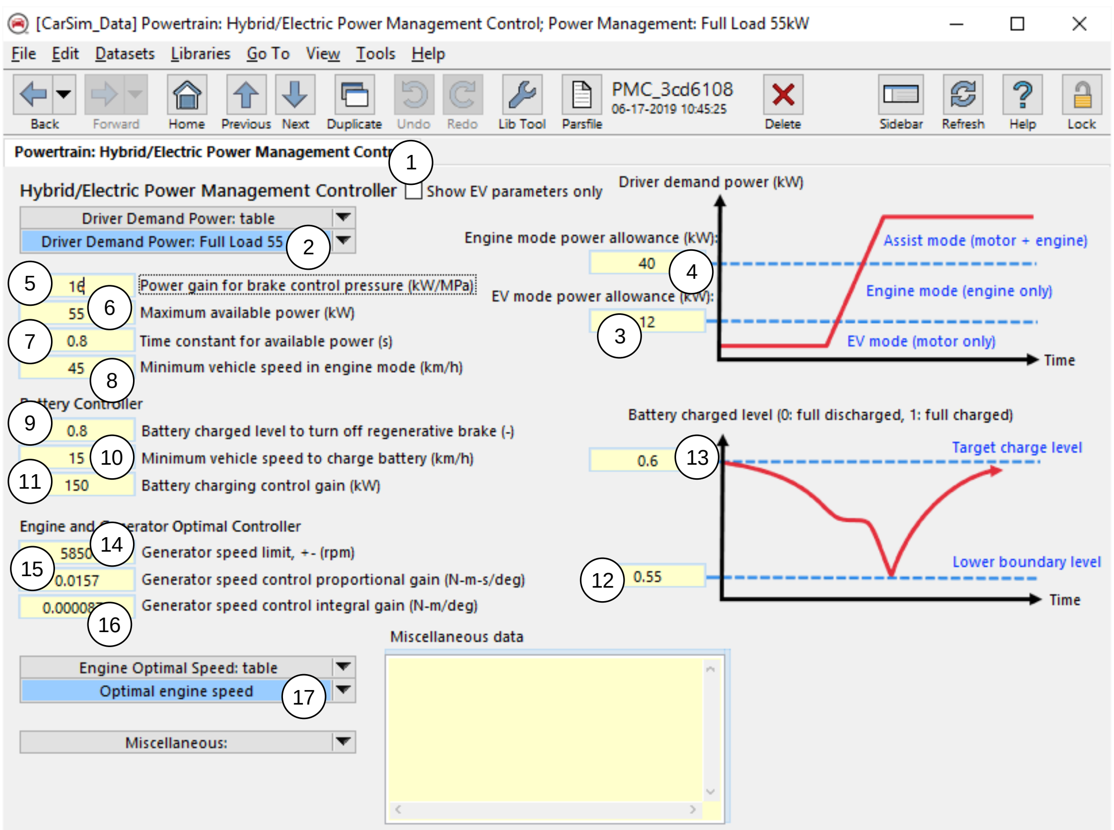


Figure 13. Powertrain: Hybrid/Electric Power Management Control screen for HEV.

Power Management Controller

The power management controller outputs the torque command (T_{cmd}) for each of the electric motor and generator (see equation 1) and engine throttle command by switching four different power modes (output variable: `ModeHybr`):

1. EV mode: drive with motor only (`ModeHybr`=1),

2. Engine mode: drive with engine only (`ModeHybr`=2),
3. Assist mode: drive with motor + engine (`ModeHybr`=3), and
4. Brake mode: regenerative brake with motor (`ModeHybr`=0).

The mode is switched based on how much the power required for the hybrid powertrain system from the driver (P_{drv}) which is defined differently on driving, braking with closed-loop speed control, or braking with open-loop speed control. On the driving condition, the required power is defined by table, f_{Pdrv}, as a function of the throttle input from the driver (the configurable function is linked ②):

$$P_{drv}=f_{Pdrv}(\text{throttle}) \quad (P_{drv}\geq 0, \text{driving condition}) \tag{27}$$

while the required power on braking depends on either closed-loop or open-loop control such as:

$$P_{drv}=P_{SC} \quad (P_{drv}<0, \text{braking with closed loop})$$

$$P_{drv}=-1\cdot P_{bkcon}\cdot K_{Pbk}\cdot|\tanh(C_{fbk}\cdot V_W)| \quad (P_{drv}<0, \text{braking with open loop}) \tag{28}$$

where P_{SC} is the required power calculated by the closed-loop speed control (the output variable is `Pwr_SCrq`, settings are referred to the separate document, *Driver Controls*). P_{bkcon} is the brake master control pressure (output variable is `Pbk_Con`), K_{Pbk} is the power gain for the brake control ⑧, C_{fbk} is the control factor (parameter, `CF_HEV_PBK`, can be set by misc. field) and V_W is the average of wheel speeds.

The rule of the power mode selection is summarized below, sorted from lower to higher priority:

1. Default is **EV mode**
2. Switch to **Engine mode** if any one of the following three conditions is satisfied: the required power exceeds the maximum power allowance of EV mode ③; the vehicle speed exceeds the engine mode cut off speed ⑧; or the battery charged level on/below the lower level ⑫ with vehicle speed at least ⑩
3. Switch to **Assist mode** if the following two conditions are both satisfied: the required power exceeds the maximum power allowance of engine mode ④; and the battery state of charge level is above the lower boundary ⑫
4. Switch to **Regenerative Brake mode** if the required power is negative

The maximum available power with the HEV system ⑥ and the time constant ⑦ are only applied when the closed-loop speed controller is used to compensate the throttle input.

Note: The electric powertrain system (`OPT_HEV = 2`) always stays in the EV or regenerative brake mode (`ModeHybr` ≤ 1).

The series hybrid powertrain system (also known as range-extended electric, `OPT_HEV = 3`) always stays in the EV, engine only, or regenerative brake mode (`ModeHybr` ≤ 2), but never assist mode.

User settings

2. Link to the configurable function of driver demand power. The driver demand power is defined by a configurable function of driver throttle position.
3. Maximum power allowance operated with EV mode (keyword = `PWR_EV_MODE`).
4. Maximum power allowance operated with engine mode (keyword = `PWR_ENG_MODE`).
5. Brake power demand per master cylinder control pressure (keyword = `KPW_PBK_HEV`).
6. Maximum power available with HEV system (keyword = `PWR_HEV_DRV_MAX`).
7. Time constant for hybrid available power (keyword = `TC_PWR_HYBRID_AV`).
8. Minimum vehicle speed operated with engine mode (keyword = `VLOW_ENG_MODE`).

Battery Controller

The battery charged level is maintained by the battery controller in which the power command of battery charge (P_{ch_cmd}) is defined as:

$$P_{ch\_cmd} = \min\{|P_{btr\_Ch}|, (soc_{targ} - soc) \cdot k_{btr\_ch}\}, \ (P_{ch\_cmd} < 0 \rightarrow P_{ch_{cmd}} = 0) \qquad (29)$$

where P_{btr_Ch} is the battery charged power limit defined by equation 20, soc_{targ} is the target battery charged level 13, and k_{btr_ch} is battery charging control gain 9. The battery charge power command (P_{ch_cmd}) is then used by the engine and generator optimal controllers.

The regenerative brake is turned off when the battery charged level is more than 11.

User settings

9. Battery charging control gain (keyword = `K_BATTERY_CHARGE`).
10. Minimum vehicle speed to charge battery (keyword = `VLOW_BATTERY_CHARGE`).
11. Battery charged level to turn off regenerative brake (keyword = `REGEN_BRK_OFF`).
12. Lower boundary of battery charged level (keyword = `BATTERY_CHARGE_LOW`).
13. Target battery charged level (keyword = `BATTERY_CHARGE_TARG`).

Engine and Generator Optimal Controller

> **Note:** This sub-section is not applicable with the electric powertrain system (`OPT_HEV` = `2`.)

The required engine power (P_{eng_rq}) is defined differently in the different power modes:

$$P_{eng\_rq} = 0 \quad \text{(EV mode and brake mode)}$$

$$P_{eng\_rq} = \min(P_{drv} + P_{ch\_cmd}, P_{eng\_max}) \quad \text{(engine mode other than series hybrid)}$$

$$P_{eng\_rq}=P_{ch\_cmd} \quad \text{(engine mode with series hybrid)}$$

$$P_{eng\_rq}=P_{eng\_max} \quad \text{(assist mode)} \tag{30}$$

where P_{eng_max} is the maximum power allowance operated with engine mode ④. The optimal engine target speed (ω_{e_targ}) is defined by a function of the required engine power:

$$\omega_{e\_targ}=\max\{\omega_{e\_idle}, f_{\omega e\_optima}(P_{eng\_rq})\} \tag{31}$$

where ω_{e_idle} is engine idle speed and $f_{\omega e\_optima}$ is the configurable function linked from ⑰. The engine throttle command (output variable, `Thr_HEV`) is modulated in order to maintain the optimal engine target speed (ω_{e_targ}).

The generator target speed (ω_{gnrtr_targ}) is derived by the motor speed and engine target speed:

$$\omega_{gnrtr\_targ}= \frac{(N_r+N_s)\cdot\omega_{e\_targ}-N_r\cdot\omega_{motor}}{N_s} \tag{32}$$

where the generator target speed is limited to ⑭ for both positive and negative rotation. The generator torque command (T_{gnrtr_cmd}) is calculated as:

$$T_{gnrtr\_cmd}=K_{p\_gnrtr}\cdot(\omega_{gnrtr_{targ}} - \omega_{gnrtr}) - K_{i\_gnrtr}\cdot \int \left(\omega_{gnrtr_{targ}} - \omega_{gnrtr}\right) dt \tag{33}$$

where K_{p_gnrtr} and K_{i_gnrtr} are the generator speed control proportional ⑮ and integral ⑯ gain, respectively. The required generator power is:

$$P_{gnrtr\_rq}=T_{gnrtr\_cmd}\cdot\omega_{gnrtr} \tag{34}$$

The torque commands for the generator (T_{gnrtr_cmd}) is applied to the generator torque calculation in equation 1.

User settings

⑭ Generator speed limit (absolute value applied for both positive and negative) (keyword = `AV_GNRTR_LIMIT`).

⑮ Generator speed controller: proportional gain (keyword = `GNR_CONTROL_KP`).

⑯ Generator speed controller: integral gain (keyword = `GNR_CONTROL_KI`).

⑰ Link to the configurable function of optimal engine speed.

Motor Controller

The required motor power (P_{motor_rq}) is defined differently on the power mode such as:

$$P_{motor\_rq}=0 \quad \text{(brake mode with regenerative brake turned off)}$$

$$P_{motor\_rq}=P_{drv} \quad \text{(EV or brake mode with regenerative brake turned on)}$$

$$P_{motor\_rq}=-P_{ch\_cmd} - P_{gnrtr\_rq} \quad \text{(engine mode other than series hybrid)}$$

$$P_{motor\_rq}=P_{drv} - P_{ch\_cmd} - P_{gnrtr\_rq} \quad \text{(engine mode with series hybrid)}$$

$$P_{motor\_rq}=P_{drv}-P_{gnrtr\_rq}-P_{eng\_max} \quad \text{(assist mode)} \tag{35}$$

The motor torque command (T_{motor_cmd}) is calculated by:

$$T_{motor\_cmd}=\frac{P_{motor\_rq}}{\omega_{motor}}, \text{ (EV, engine or assist mode)}$$

$$T_{motor\_cmd}=-1\times\min\left(\left|\frac{P_{motor\_rq}}{\omega_{motor}}\right|,\left|\frac{P_{btr\_Ch}}{\omega_{motor}}\right|\right), \text{ (brake mode)} \tag{36}$$

where P_{btr_Ch} is the battery charged power limit derived by equation 20.

The torque command for the motor (T_{motor_cmd}) is used in the motor torque calculation (equation 1).

Note In CarSim and TruckSim, if the motors locate on two or more driven axles (`OPT_MOTOR_ON_AXLE=1`), the motor torque command, T_{motor_cmd}, is distributed on each of driven axles through the differential indexed parameters (`R_REAR_MOTOR_BIAS (IDIFF)`). In this case, the term of the motor speed (ω_{motor}) is replaced by the transmission output angular speed (ω_g) in equations 35 and 36.

Special Cases in CarSim and TruckSim

There are some types of electric and hybrid-electric all-wheel-drive (AWD) vehicles without any mechanical connection between the front and rear axles. Typically, two electric motors power the front and rear drive axles, and the front and rear drive torques are electrically distributed by a controller. Such an electrified all-wheel-drive system is sometimes called e-AWD.

CarSim/TruckSim support such e-AWD systems. The following sub-sections describe how to specify the datasets for each of these hybrid-electric and electric all-wheel-drive vehicles.

Hybrid-Electric AWD (Hybrid e-AWD)

Figure 14 shows a diagram of the hybrid-electric AWD system in which a hybrid-electric powertrain unit (an engine with an electric motor) is directly connected on the front axle and two independent electric motors power the left and right rear wheels.

In this system, as the electric motors are on the drive axles, the checkbox **Motors on driven axles** on the **Powertrain: Hybrid/Electric System** screen (2 in Figure 4) should be checked. The electric motors on the drive axles are specified on each of the **Powertrain: Front Differential** and **Powertrain: Rear Differential** screens as shown in Figure 15 and Figure 16, respectively. Each of the **Front** and **Rear Differential** screens have a dropdown menu (below) to select either no electric motor, one electric motor on center, or two electric motors on both sides.

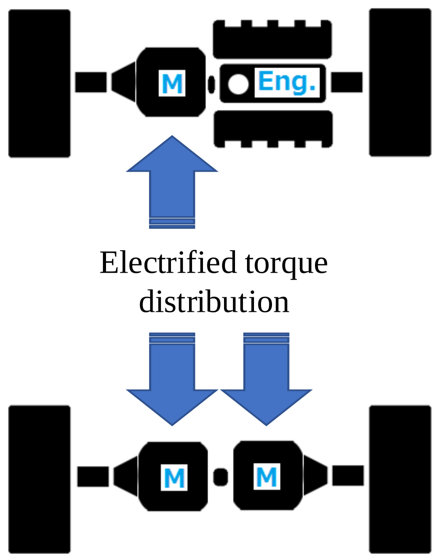
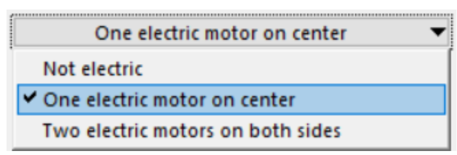


Figure 14. Example Hybrid-Electric AWD system diagram.



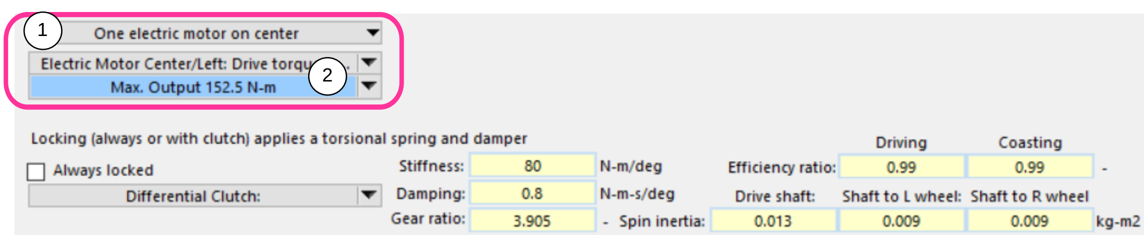


Figure 15. Specifying an electric motor on the Powertrain: Front Differential screen.

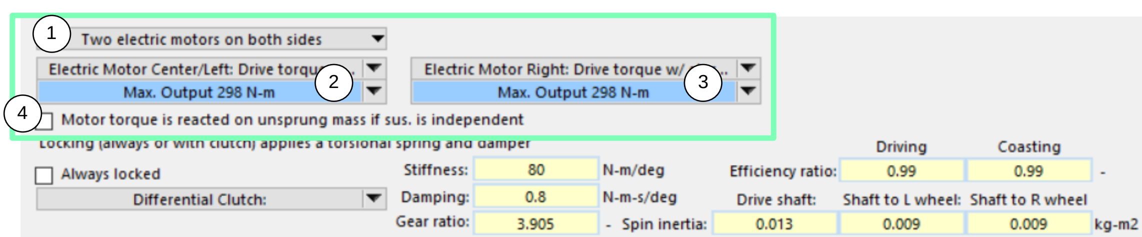


Figure 16. Specifying two electric motors on wheels on the Powertrain: Rear Differential screen.

If one electric motor is selected by the dropdown menu (1) (in Figure 15 and Figure 16), a blue field for the center electric motor (2) is displayed. On the other hand, if two electric motors are selected in the menu, the electric motor (2) is applied to the left wheel and an additional blue field for the right wheel (3) is displayed. By selecting two motors, a checkbox (4) appears. Check this box to specify that the motor torque is reacted by the unsprung mass if the suspension type is independent. For example, if the motors are located on the wheel carriers or wheel hubs (i.e., in-wheel motor), the box should be checked. On the other hand, if the motors are located on the chassis, the box should be unchecked.

Note: In case of a solid-axle suspension, the motor torque is reacted by the unsprung mass regardless of the setting of this checkbox.

Figure 17 shows the **Powertrain: Transfer Case** screen to specify the mechanical and electrical torque distribution for an HEV e-AWD system. The screen has a dropdown menu (Figure 18) to select either a mechanical, electro-mechanical, or an electrical (EV) system.

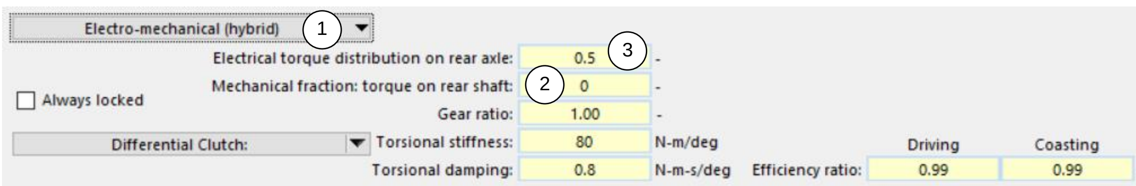


Figure 17. Example torque fraction on the Powertrain: Transfer Case screen for HEV e-AWD.

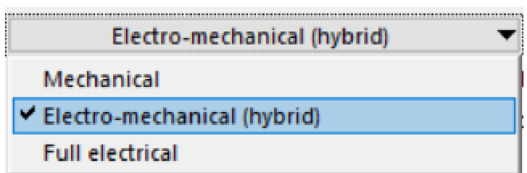


Figure 18. Options for type of torque transfer.

Because the hybrid-electric powertrain unit is directly connected to the front axle wheels, the mechanical torque fraction on the rear shaft (2) should be set to zero (Figure 17). In this way, the output torque from the hybrid-electric powertrain unit is 100% applied to the front axle and the angular speed of the powertrain is calculated based on the front axle.

The electrical torque distribution on the rear axle (3) is to specify the torque distribution between the front and rear electric motors on the drive axles. The example dataset shown in Figure 17 specifies 50/50 torque distribution between the front and rear. The value is also importable from the Simulink and VS Commands through the import variable, `IMP_R_REAR_MOTOR_BIAS_D3`.

Some types of hybrid-electric all-wheel-drive vehicles actively distribute the drive torque between the front and rear depending on the driving condition as shown in Figure 19. Figure 20 shows an example VS Command script which reproduces this type of torque distribution system.

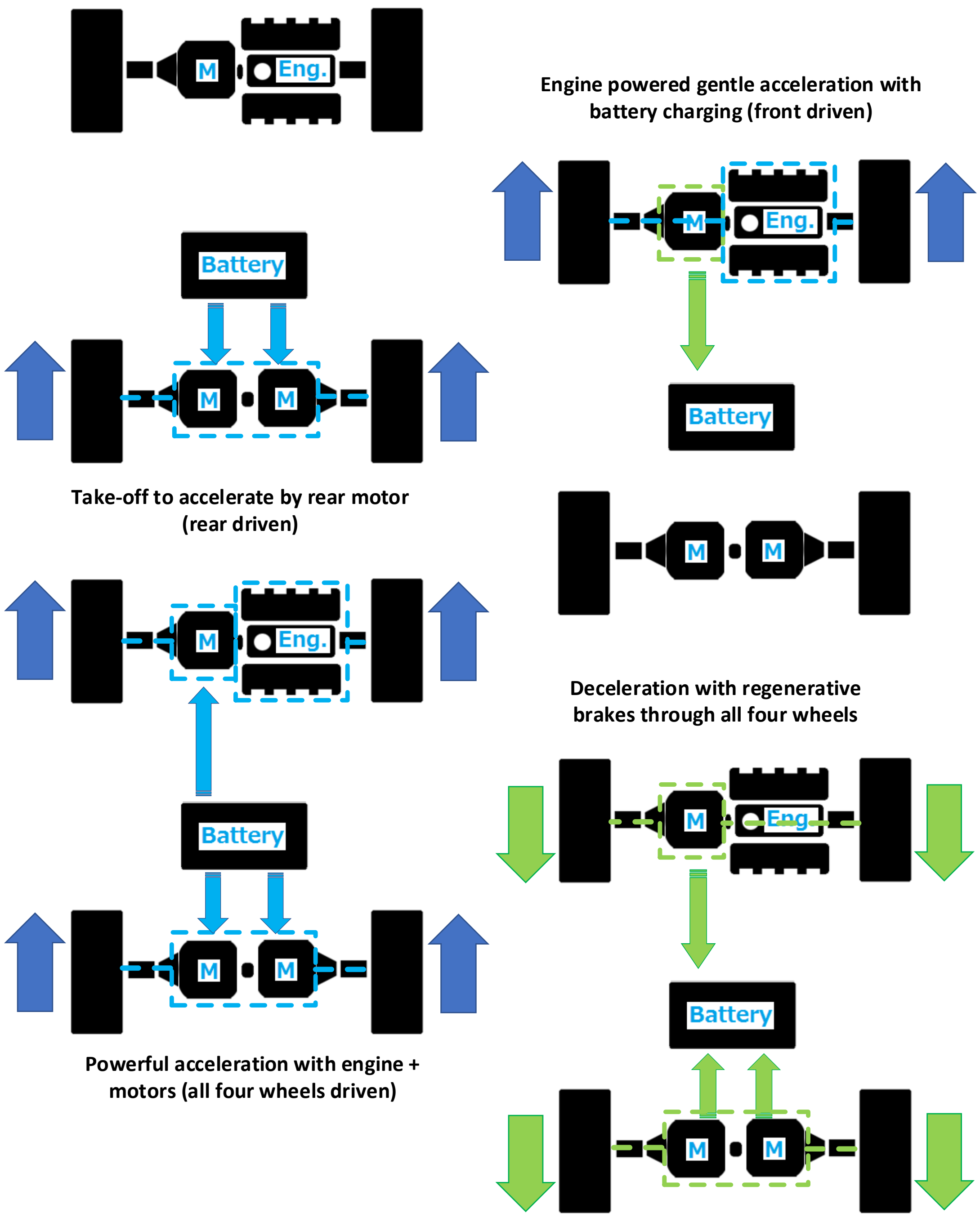
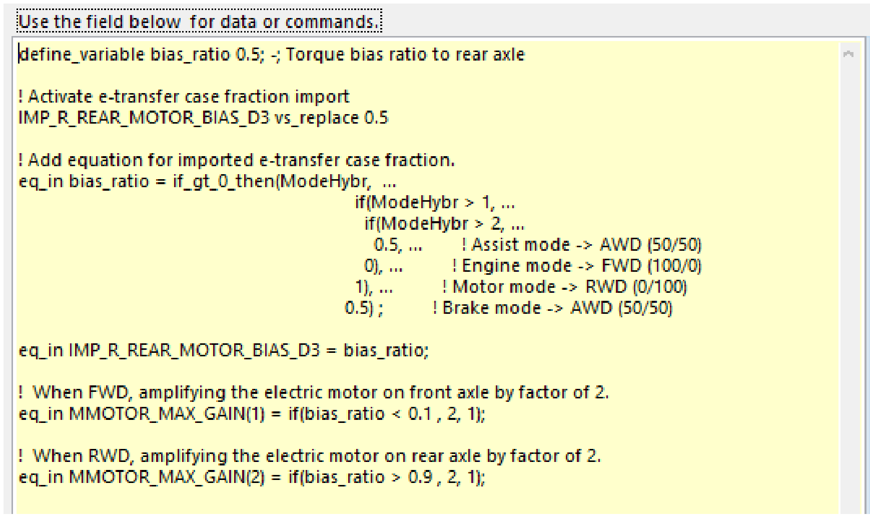


Figure 19. Active torque distribution of e-AWD with various driving condition.



Use the field below for data or commands.

```
define_variable bias_ratio 0.5; -; Torque bias ratio to rear axle

! Activate e-transfer case fraction import
IMP_R_REAR_MOTOR_BIAS_D3 vs_replace 0.5

! Add equation for imported e-transfer case fraction.
eq_in bias_ratio = if_gt_0_then(ModeHybr,  ...
                                          if(ModeHybr > 1, ...
                                           if(ModeHybr > 2, ...
                                            0.5, ...      ! Assist mode -> AWD (50/50)
                                           0), ...        ! Engine mode -> FWD (100/0)
                                          1), ...         ! Motor mode -> RWD (0/100)
                                         0.5) ;           ! Brake mode -> AWD (50/50)

eq_in IMP_R_REAR_MOTOR_BIAS_D3 = bias_ratio;

!  When FWD, amplifying the electric motor on front axle by factor of 2.
eq_in MMOTOR_MAX_GAIN(1) = if(bias_ratio < 0.1 , 2, 1);

!  When RWD, amplifying the electric motor on rear axle by factor of 2.
eq_in MMOTOR_MAX_GAIN(2) = if(bias_ratio > 0.9 , 2, 1);
```

Figure 20. Example VS Command script reproducing an active torque distribution of e-AWD.

Electric AWD (e-AWD)

Typically, electric AWD systems have two electric motors — one is on the front axle and the other is on the rear axle — and therefore a mechanical connection between the two axles does not exist as shown in Figure 21. Like the hybrid-electric AWD system described in the previous sub-section, the checkbox **Motors on driven axles** on the **Powertrain: Hybrid/Electric System** screen (2 in Figure 4) should be checked. The front and rear electric motors need to be specified on the **Powertrain: Front Differential** screen and **Powertrain: Rear Differential** screen, respectively.

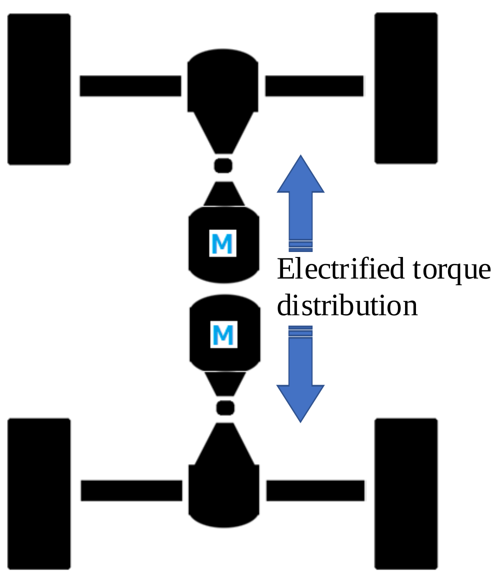


Figure 21. Example electric AWD system diagram.

The dropdown menu 1 should be set to **full electrical** on the **Transfer Case** screen (Figure 17), and the electrical torque distribution between front and rear electric motors can be specified by the field 3. The torque distribution is also controllable by an import variable, `IMP_R_REAR_MOTOR_BIAS_D3`.

Note	When the dropdown menu 1 is set as **full electrical** on the **Powertrain: Transfer Case** screen (see Figure 17), the mechanical torque fraction parameter 2 is not displayed. However, the default value of 0.5 is applied to calculate the rotational speed of the motor controller.

Examples

Simple open-loop acceleration and regenerative brake with HEV (RWD)

Figure 22 shows the simulation result from a simple procedure: beginning with zero speed, linearly increase pedal throttle in 10 second, followed by coasting for 5 second and then applying the brake. Four plots involve: throttles (driver's pedal and HEV control), powertrain torques (engine, motor, generator and HEV output), hybrid power mode and battery state of charge. As you can see in the figures, the vehicle begins with EV mode followed by engine and assist mode during the acceleration. The battery level is decreased during the acceleration while the battery is re-recharged by the negative motor torque during the deceleration.

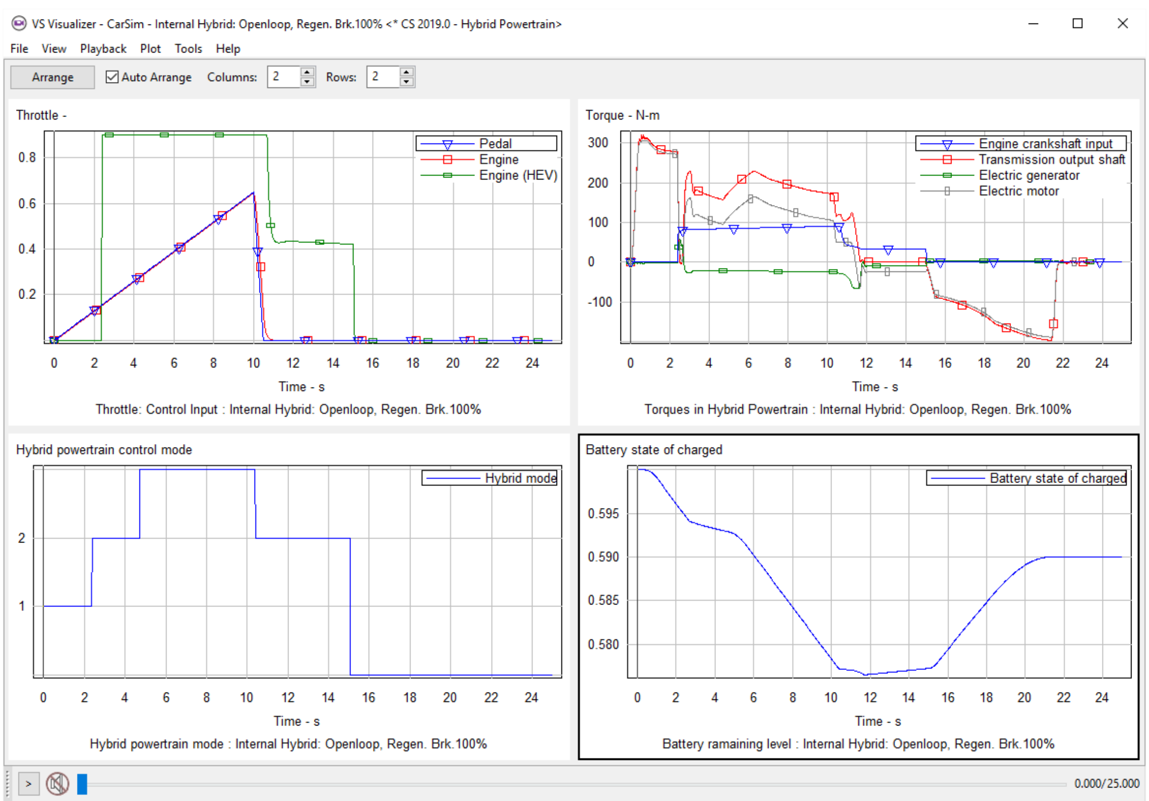


Figure 22. Time history plots of the throttles (driver's pedal and HEV control), powertrain torques, power mode and battery state of charged during a simple acceleration and brake.

EPA cycle maneuver with HEV (RWD)

Figure 23 shows an EPA urban cycle maneuver which takes 1369 seconds of the simulation. The maximum speed is about 57km/h but mostly the car repeatedly stops-and-goes under 35km/h.

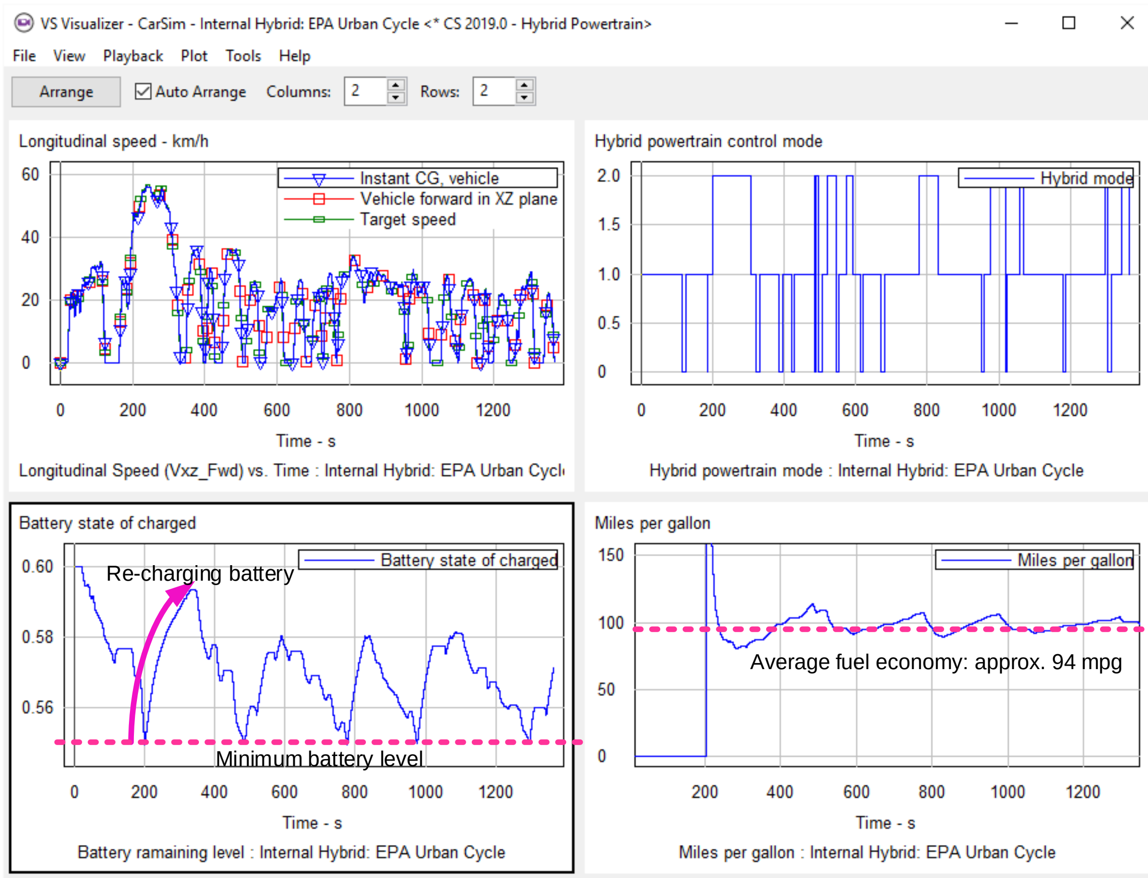


Figure 23. Time history plots: vehicle speed, drive mode, battery level and fuel economy (EPA urban).

Four plots involve: the vehicle speed, hybrid power mode, battery state of charge and fuel consumption rate (MPG: miles per U.S. gallon). As shown in these plots, the battery level is kept between 60% as initial and 55% as minimum with various drive modes. The average fuel consumption rate is approximately 94 MPG (= 39.6 km/litter) which relates a typical hybrid powertrain small size passenger car.

Input and Output Variables

Table 2 and Table 3 list input and output variables associated with the BEV/HEV, respectively.

Table 2. Input variables for the built-in BEV/HEV.

Name	**Units**	**Description**
IMP_ENGINE_CMD_HEV	V	Engine command from HEV controller
IMP_HYBRID_MODE	-	HEV control mode: 0 -> brake, 1 -> motor, 2 -> engine, 3 -> engine + motor
IMP_M_GNRTR	N-m	Electric generator output torque to planetary sun gear
IMP_M_GNRTR_CMD	N-m	Electric generator torque command
IMP_M_MOTOR	N-m	Electric motor output torque to planetary ring gear
IMP_M_MOTOR_D1	N-m	Electric motor output torque of front differential
IMP_M_MOTOR_D2	N-m	Electric motor output torque of rear differential
IMP_M_MOTOR_CMD	N-m	Electric motor torque command
IMP_M_MOTOR_CMD_D1	N-m	Electric motor torque command of front differential
IMP_M_MOTOR_CMD_D2	N-m	Electric motor torque command of rear differential
IMP_R_REAR_MOTOR_BIAS_D3	-	Fraction: motor torque command on rear driveshaft at e-AWD
IMP_TEMP_BTTRY	C	Battery temperature

Notes In TruckSim, the input variables of the electric motors on drive axles (M_MOTOR_ and M_MOTOR_CMD_) are supported up to 5th drive axle with the suffix of D4, D5, and D8. And the input variables of the motor torque distribution command at inter-axles (R_REAR_MOTOR_BIAS_) is supported up to 5th drive axle with the suffix of D6, D7, and D9.

In TruckSim, the output variables of the electric motors on drive axles (AV_Mt_, M_MtC_, M_Mtr_, PwMtC_, and PwrMt_) are supported up to 5th drive axle with the suffix of D4, D5, and D8.

Table 3. Output variables for the built-in BEV/HEV.

Name	Units	Description
AVtrgEng	rpm	Engine target speed in HEV
AVtrgGnr	rpm	Generator target speed in HEV
AV_GNRTR	rpm	Electric generator sun gear spin
AV_Motor	rpm	Electric motor ring gear spin
AV_Mt_D1	rpm	Electric motor spin on front differential
AV_Mt_D2	rpm	Electric motor spin on rear differential
A_Bttry	W/V	Battery output current
CapBtrDs	A-h	Battery discharged capacity
EffBttry	-	Battery efficiency
ModeHybr	-	Hybrid powertrain control mode
M_GnrCmd	N-m	Electric generator torque command
M_Gnrtr	N-m	Electric generator output torque
M_MotCmd	N-m	Electric motor torque command
M_MtC_D1	N-m	Electric motor torque command on front diff.
M_MtC_D2	N-m	Electric motor torque command on rear diff.
M_Motor	N-m	Electric motor output torque
M_Mtr_D1	N-m	Electric motor output torque on front differential
M_Mtr_D2	N-m	Electric motor output torque on rear differential
PwrBtrCh	kW	Battery charged power limit
PwrBtrDs	kW	Battery discharged power limit
PwrBttry	kW	Electric battery required power
PwrDrHEV	kW	Driver required power in BEV/HEV
PwrEngRq	kW	Required engine power in HEV
PwrGnrtr	kW	Electric generator output power
PwrMotDm	kW	Electric motor power demand
PwMtC_D1	kW	Electric motor power command on front differential
PwMtC_D2	kW	Electric motor power command on rear differential
PwrMotor	kW	Electric motor output power
PwrMt_D1	kW	Electric motor output power on front differential
PwrMt_D2	kW	Electric motor output power on rear differential
ResBttry	V2/W	Electric battery resistance
SocBttry	-	Battery state of charged
Thr_HEV	-	Engine throttle command from HEV
VocBttry	V	Battery open-circuit voltage
V_Bttry	V	Battery output voltage
TempBttry	C	Battery temperature