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Simulation Hybrid Electric Vehicles Using Model Based Design

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Summary

This paper presents a model-based design methodology based on using “Powertrain Energy Estimator” approach to simulate and analyze the performance of Hybrid Electric Vehicles (HEV’s) having either series or parallel driving modes. Two different vehicles platform models considered to simulate the HEV’s and evaluate the vehicle performance, powertrain components energy, total energy consumption during FTP (EPA75) drive cycle. The first model represents a typical passenger series HEV and the second is a model of parallel HEV for a commercial 10 meters transit bus.

Keywords: Simulation, Modelling, HEV (hybrid electric vehicle), Vehicle Performance, Energy Consumption.

1 Introduction

Most OEM’s require that all new and modified powertrain components designs used for any conceptual vehicle be verified using modeling, simulation and performance analysis before final approval. Many Computer-Aided Engineering (CAE) simulation tools, such as GT-Power, Autonomie, Velodyn, Adviser and others are available for modeling, simulation and performance analysis of the vehicle’s and their powertrain components. The Powertrain Energy Estimator (PEE) approach [1] is an Add-On for Matlab/Simulink/Stateflow, which serves as a simplified and fast methodology that provides a user-friendly option to meet the requirements of automotive engineering throughout the development of vehicle’s powertrain modeling, simulations and performance analysis. The Environmental Protection Agency (EPA) is mainly concerned with the impact of conventional Internal Combustion Engine (ICE) vehicles on air quality in urban areas. HEV’s combines at least two energy converters from ICE and traction Electric Motors (E-Motors) drives to provide the equivalent power demand, drive mileages range and safety similar to a conventional ICE vehicle, while reducing fuel consumption and harmful emissions [2]. The ICE used in HEV allow a wider driving range and also provide additional torque when higher torque is required during fast vehicle acceleration or steep hill climbing. The power from ICE in HEV divides along two paths (series and parallel): In series Hybrid mode, when the battery power capacity-State Of Charge (SOC) level is low, the ICE drives a generator and provides an “electrical” power to the traction E-Motor and/or charge the high voltage battery pack. In parallel Hybrid mode, when the power demand is high and/or the battery power capacity (SOC) is low and the power produced by the E-Motor is not enough to achieve the required propulsion power demand to drive the vehicle, the ICE provides the additional required power to the wheels during the driving cycle. However, the HEV’s have several disadvantages including the increase in vehicle mass, components, costs, power electronics and potentially a lower reliability due to the complexity of the overall powertrain control managements [2].

2 Components of Hybrid Electric Vehicle

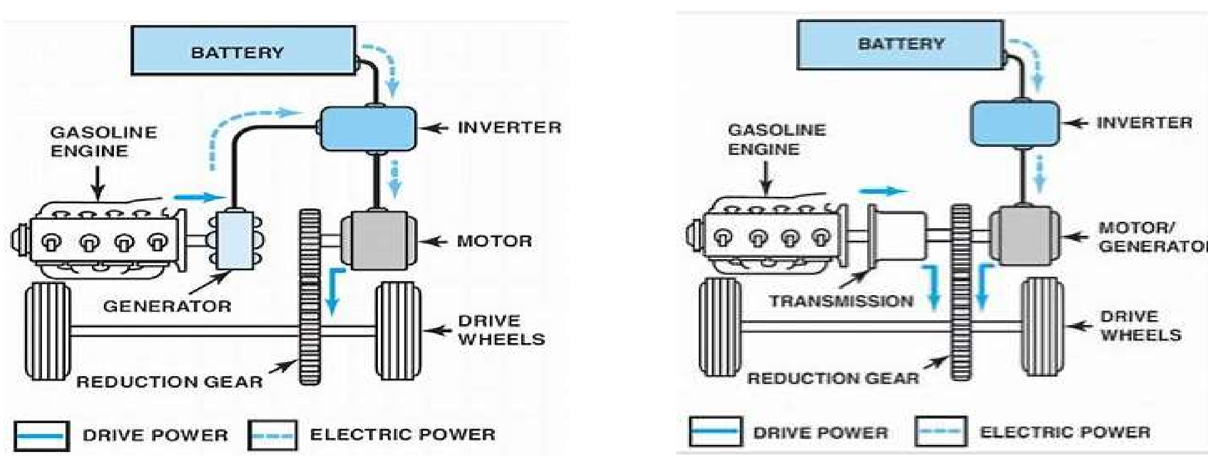
The main components of the two configuration types of HEV's are shown in Figure 1:

2.1 Series HEV

In series HEV, the E-Motor only supplies power to propel the vehicle. The engine drives a generator within its optimal operation range to provide the energy to the storage system (battery) when it needs to be charged. One main advantage of the series configuration is that the engine and vehicle speeds are decoupled so the engine can run at its optimum, greatly reducing fuel consumption. In this configuration, the E-Motor is the only one connected to the wheels and sized to achieve the target vehicle performance (sustain the road grade ability, maximum vehicle speed and acceleration time). The engine and generator are sized only to maintain the power capacity (SOC) of the battery pack higher than the required limit to power the E-Motor to drive the vehicle [2].

2.2 Parallel HEV

In parallel HEV, both the E-Motor and the engine have a mechanical connection to the wheels. The E-Motor and engine are both coupled directly to the wheels by transmission gearbox/clutch/differential axles, and can share the high power demand during fast vehicle accelerations or grade climbing [2]. Therefore, it is possible to downsize both the E-Motor and the engine compared to series Hybrid configuration. The engine power capacity is initially determined by the power demand in steady driving conditions with a constant cruising speed. The engine must deliver enough power to meet the vehicle power demand, which includes the rolling resistance power and the aerodynamic drag power. The E-Motor power size depends on the power demand during dynamic driving, such as fast acceleration and maximum grade ability requirements. Since the engine speed is linked to the vehicle speed, the engine can operate close to its best efficiency curve only under certain conditions. However, using power from both the E-Motor and the engine to propel the vehicle increases the efficiency as compared to the series configuration during most operating conditions [2]. The E-Motor can be located anywhere between the output engine shaft and the wheels.



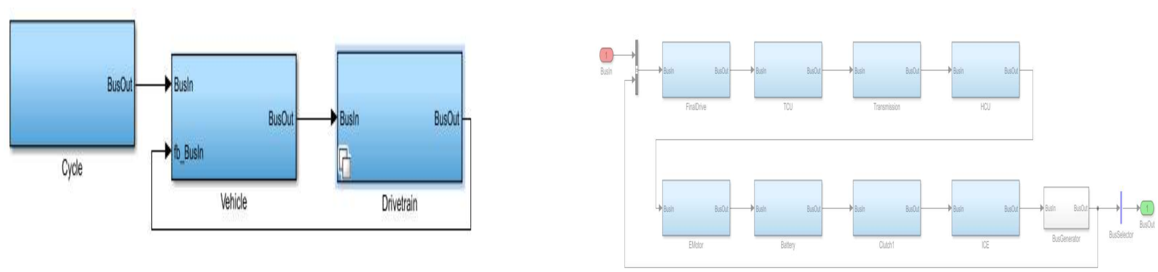
(a) Series HEV (b) Parallel HEV

Figure1. Components of series/parallel HEV's

3 Powertrain Energy Estimator (PEE)

This section briefly describes the top-level configuration of the PEE development to simulate and analyze the performance of any conceptual conventional (ICE) vehicles, Pure Electric Vehicles (PEV's) [1] and Hybrid Electric Vehicles (HEV's series or parallel) platform and their powertrain components. The PEE approach is a model-based design used for simulations and does not require any building or compilation steps. It is flexible enough to operate on most computers in commercially available MATLAB/Simulink/Stateflow graphical/object-oriented software environments. The main advantages of using PEE simulation are to simplify the usage and the development of any conceptual vehicles and their powertrain models. Users can easily create and update the overall vehicle model by selecting the powertrain components types, sizes and parameters with different drive cycles from various files that can be loaded and saved to update the complete plant model.

Figure 2-a, shows the top level Simulink plant model blocks builder used to simulate and analyze the performance of any conceptual vehicles, which includes the drive cycles, vehicle dynamic specifications and all drivetrain components blocks as illustrated in Figure 2-b.



(a) Simulink plant model blocks.

(b) Drivertrain components blocks.

Figure2. HEV Simulink plant model

Figure 3 shows the Graphical User Interaction (GUI) setup for the PEE used to simulate any conceptual vehicles and their powertrain models. The PEE contains different sections that are used to specify the parameterization of the vehicle dynamic specification and their powertrain components with various drive cycles. The model for each powertrain component can be easily created and updated, manually or from excel sheets loaded and saved with the new component parameters. Figures 4a and 4b show the templates setup used to parameterize the powertrain models required for engine (ICE) and E-Motor.

The simulation results obtained by using PEE generate various profiles in graphical forms representing the performance of the predicated torques, speeds, voltages, efficiency and power passed from one component to other and saves all the results in database for further user's analysis. The graphical performances will be presented in the applications section.

4 Applications

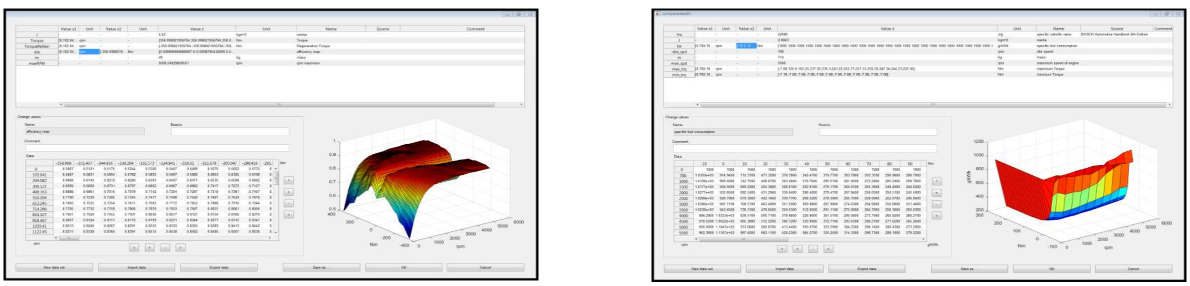
To demonstrate the PEE simulation approach, two different vehicles platform models covers the series and parallel HEV's were considered:

4.1 Simulation Series HEV

A typical passenger series HEV [3] with all vehicle dynamic specification and powertrain components parameters used to simulate this model are summarized in Table 1.

The control strategy designed inside the supervisor Hybrid Controller Unit (HCU) for this application is mainly based on calculating the required propulsion power to follows the desired FTP (EPA75) drive cycle, which mainly passes from 50/25 kW (Peak/Rated Power) traction E-Motor mounted on single-speed transmission gearbox connected to the front wheels using 4.1 differential final drive axle ratio. The E-Motor powered by a NiMh battery pack having 120 Ah with starting power capacity (SOC = 48%). The 4-cylinders with1.4L/1400 cc Diesel BMEP engine operating close to its best efficiency at 2500rpm drives a 30 kW generator to provide the "electrical' power to drive the traction E-Motor and/or charge the battery pack above the limit (SOC > 50%).

Figure3. Top level GUI setup for PEE



(a) ICE

(b) E-Motor

Figure4. Templates created to model the ICE and E-Motor

4.1.1 Simulation Results

The simulation results illustrated in Figures 5-11, show the performance of each powertrain components obtained by using FTP (EPA75) drive cycle.

It was noticed from Figures 5-7, when the vehicle started to move while the battery capacity level (SOC = 48%) was below the limit (50%), the engine started to drive the generator within its optimal operation range to provide an "electrical" power to the traction E-Motor to drive the vehicle and charge the battery pack. When the SOC reached above 50%, the charging strategy from the engine/generator stopped. However, due to high propulsion power demand especially during vehicle acceleration, it was noticed from Figures 6 and 7, the control strategy turned on/off the engine and drove the generator to charge the storage system and keep the SOC level above the reference limit. In addition, when the vehicle speed dropped while braking during the drive cycle, Figure 11 shows the regenerative braking system energy added to the storage system by the E-Motor functioning in a regenerating mode as shown in Figures 8 and 9.

Table 2 shows the powertrain components energy and the total energy consumption used during FTP-EPA75 (17.7 km) driving cycle.

Table1. Vehicle dynamic and powertrain specifications

Series HEV Vehicle Specification	
Drive Type	RWD
Final Drive Ratio	4.1
Vehicle Mass (Kg)	1500
Wheelbase (m)	3.3
Aero Drag Coefficient	0.31
Air Density Coefficient	1.2
Road Rolling Resistance	0.015
Front Area (m^2)	4
Dynamic wheel radius(m)	0.289
Inertia of Wheels(kgm^2)	1.25

Series HEV Components	
Engine	Engine Size= *1400 cc*
	Engine Type = *Diesel BMEP CI-Engine*
Generator	Peak Power Rating= 30Kw
	Maximum Speed= 6500 rpm
Traction Motor	Peak Power Rating= 50Kw
	Maximum Speed =6000 rpm
Battery	Battery Type= NiMh
	Battery Capacity = 120 Ah

Table2 Powertrain energy during FTP drive cycl

Series HEV		
Powertrain Components		Energy (kWh)
CI-Engine	Fuel Input Energy	0.41
Generator	Regeneration Input Energy	1.01
E-Motor	Regeneration Input Energy	0.8
Battery	Input Energy	1.81
	Output Energy	3.3
	Consumption Energy	1.51

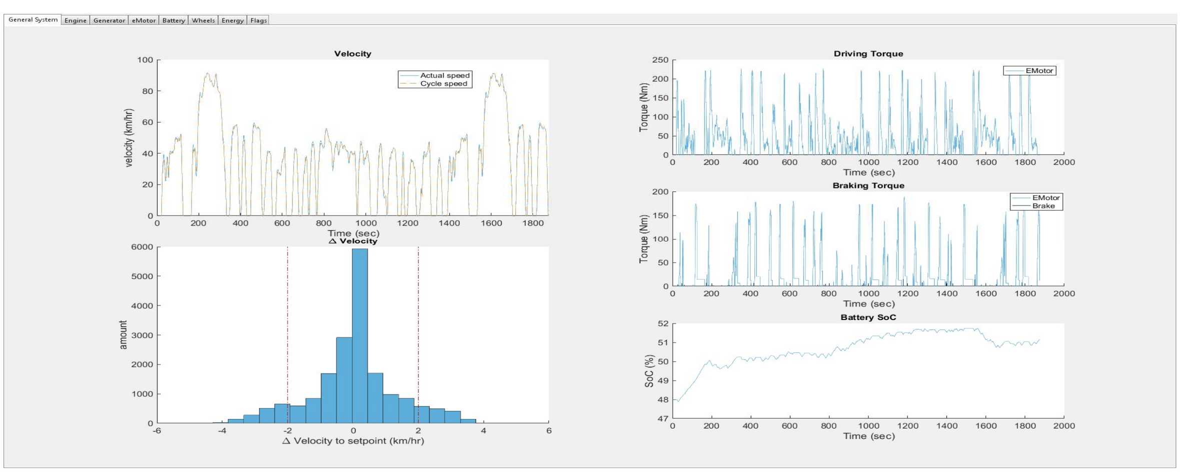


Figure5. General vehicle performance

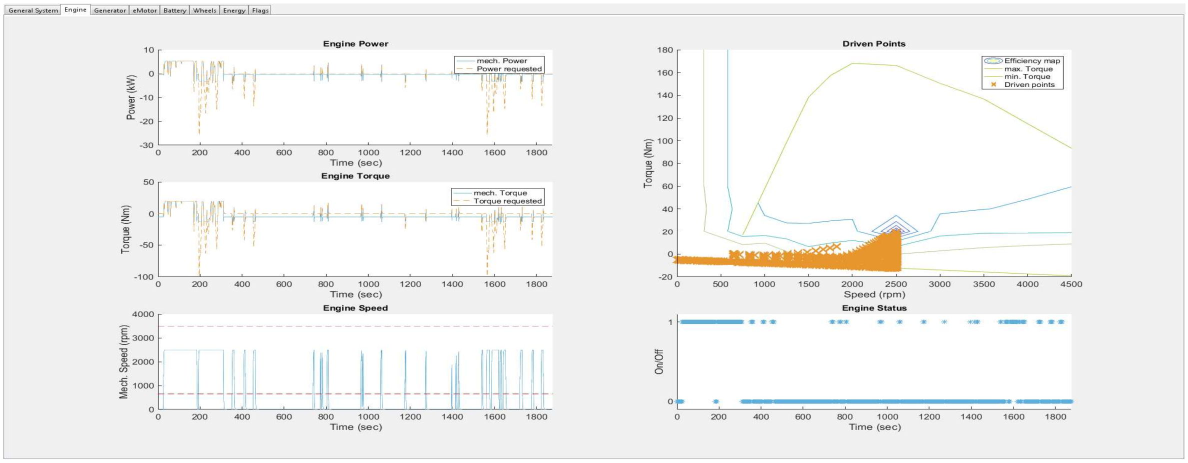


Figure6. Engine performance

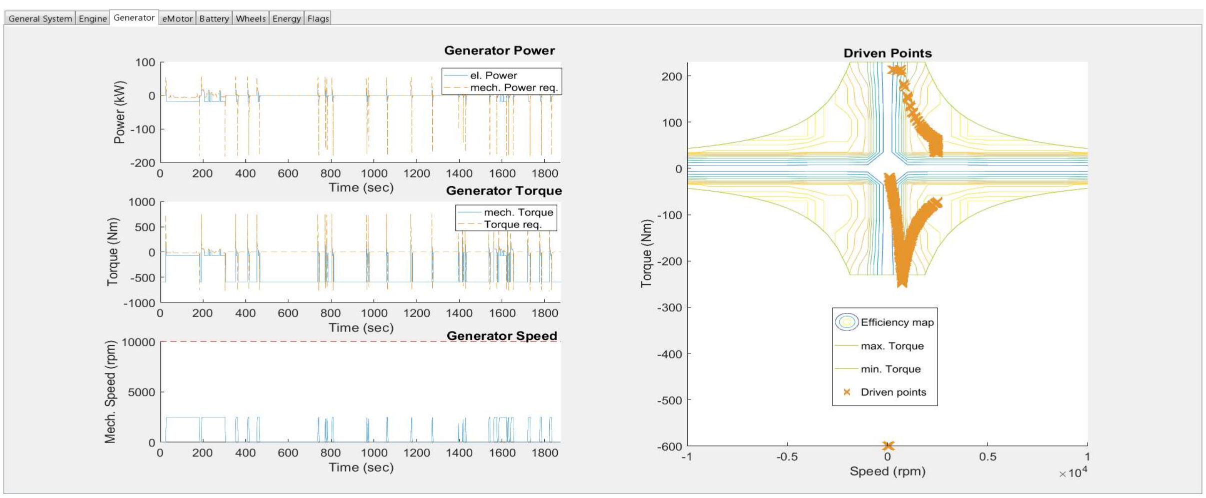


Figure7. Generator performance

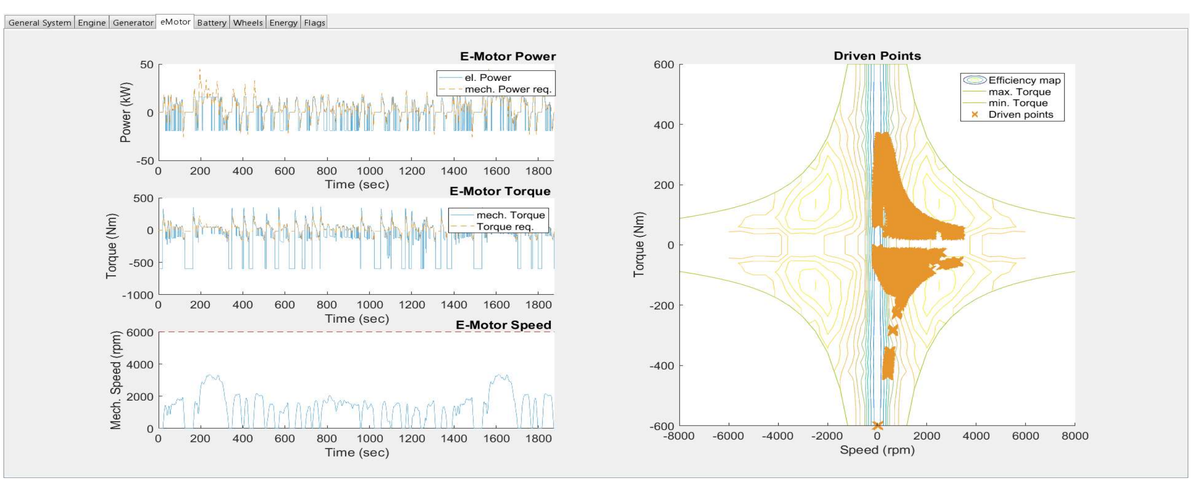


Figure8. E-Motor performance

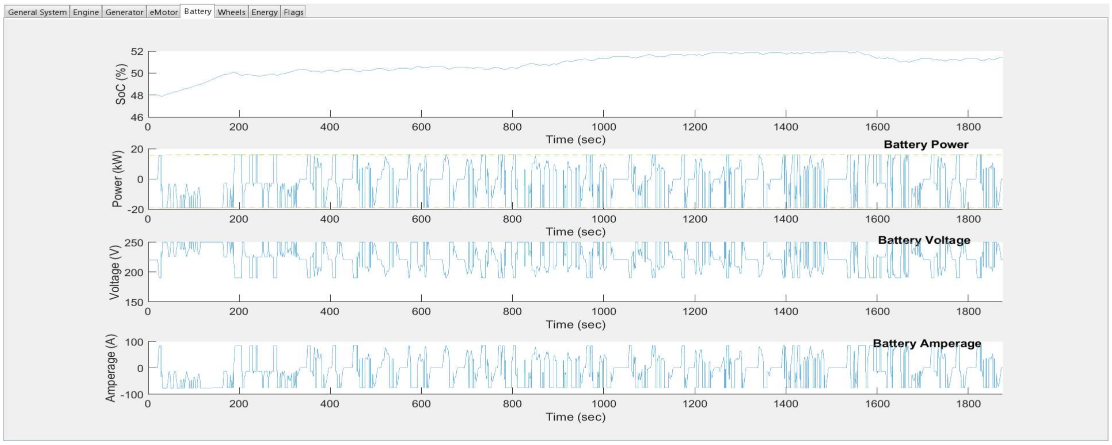


Figure9. Battery performance

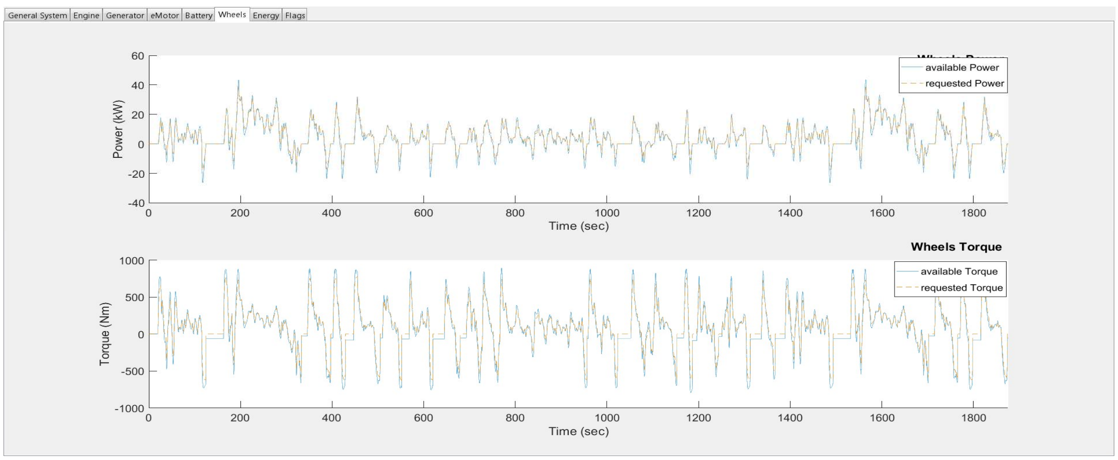


Figure10. Wheels performance

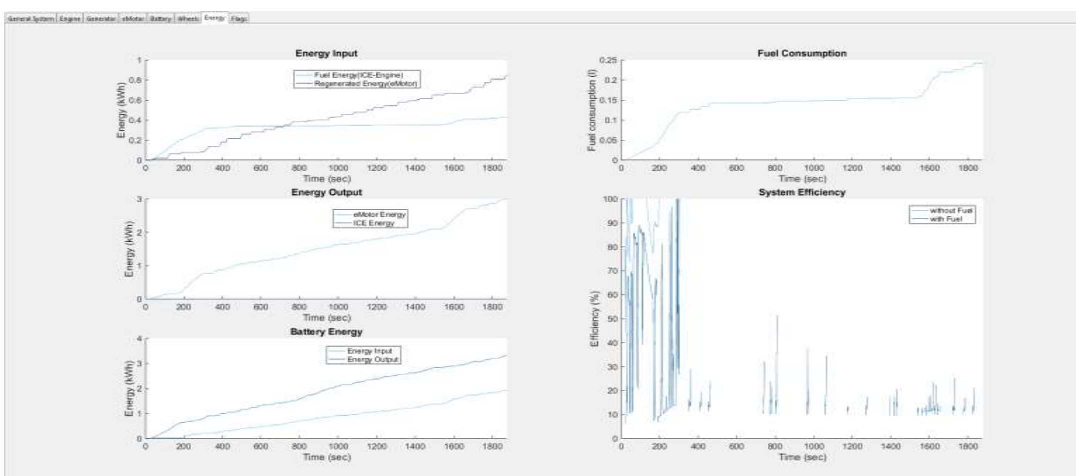


Figure11. Energy performance

4.2 Simulation Parallel HEV

The simulated model used for the parallel HEV, is representing a commercial 10 meters transit bus shown in Figure 12 [1]. All vehicle specifications and powertrain components parameters are available as listed in Table 3 [1].

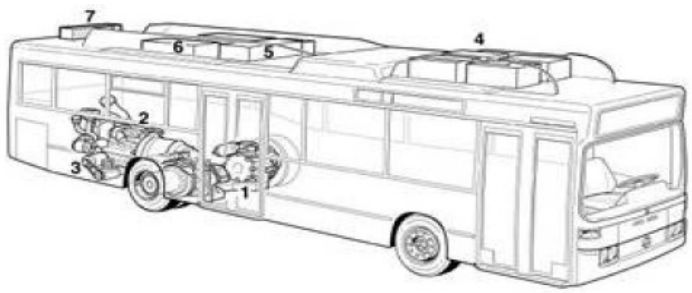


Figure 12 Typical commercial transits bus

The 140 kW E-Motor mounted on efficient 4-speed Eaton AMT transmission gearbox connected to the rear wheels with 6.2 differential final drive axle ratios and powered by Altair Nano battery with 60 Ah capacity power. The vehicle model was configured in this paper as parallel HEV by including a 2.5L/2500cc TDI engine [4] coupled in parallel with traction E-Motor to share the propulsion power demand during the drive cycle when high propulsion power demand required and/or the battery power capacity (SOC) level is low.

Remark (1): It was assumed for this application; when the vehicle started to move, the power provided from the traction E-Motor was limited due to the low initial battery capacity (SOC = 60%) and was not enough to achieve the propulsion power demand required to drive the vehicle. This assumption allowed us to see how the parallel HEV can combine the power from both drive components (engine and E-Motor) to achieve the high propulsion power demand to drive the rear wheels and avoid dropping the SOC below the limit < 50%.

Remark (2): It should also noted that for this application; a proper efficient 4-speeds transmission gear ratio designed by Eaton were selected such that both drive components (engine and E-Motor) can operate close to their best efficiency regions of operation during vehicle drive cycle, which greatly improved the total system energy efficiency and reduced fuel consumption.

Therefore, the control strategy points designed inside the supervisor Hybrid Controller Unit (HCU) for this application is mainly based on calculating the required propulsion power demand during FTP(EPA75) drive cycle and managed the distribute the torque to both drive components. In order to avoid dropping the SOC below the limit and to keep both drive components operating close to their best efficiency region, the output power from the E-Motor was limited, the hydraulic separation clutch locked and the engine operated in parallel mode adding the rest of the power required to drive the rear wheels.

4.2.1 Simulation Results

The performances of the vehicle and their powertrain components obtained from the simulation during the FTP (EPA75) drive cycle are shown in Figures 13-18. It was noticed from Figures 13 and 15, the level of SOC decreased slightly when the vehicle started to move and the traction E-Motor produced a limited torque that was not enough to meet the higher propulsion power demand required for the driving cycle speed. In order to meet the driving cycle speed and keeping the battery capacity level (SOC) from dropping below the limit (50%), the hydraulic separation clutch locked and the engine was running as shown in Figure 14 to generate additional torque to meet the propulsion power demand. The SOC remained above the limit as shown in Figure 16, but decreased at high vehicle speed when both engine and E-Motor operated close to their best efficiency region. In addition, when the vehicle speed steeply dropped while braking, the SOC level dramatically increased due to the regenerative braking system recovered from the E-Motor functioning in regenerating mode to supply the “electricity” power to charge the battery pack as shown in Figures 16 and 18.

Table3. Vehicle dynamic and powertrain specifications

Vehicle Specification	
Vehicle Platform	10 Meters Transit Bus
Vehicle Mass (kg)	15422
Wheelbase (ft.)	20'3"
Aero Drag Coefficient	0.65
Air Density Coefficient	1.2
Road Rolling Resistance	0.00532 /000144
Front Area (m^2)	6.67
Dynamic Wheel Radius(m)	0.5
E-Motor Specification	
EM-Type	Permanent Magnet Synchronous
Max. Motor Speed(rpm)	6000
Max. Motor Power(kW)	140
Motor Peak Torque (Nm)	700
HV-Battery Specification	
HV-Type	Lithium Titanate
Capacity Power (Ah)	60
(SOC) - Initial / Limit	60% / limit > 50%
Battery Manufactured	Altair Nano
Transmission Gearbox/Axle Specification	
Vehicle Drive	RWD
Transmission Gearbox	Four Speeds (AMT Eaton)
Final Drive Ratio	6.2

Table 4 shows the powertrain components energy and the total energy consumption used during FTP-EPA75 (17.7Km) driving cycle.

Table4 Powertrain energy during FTP drive cycle

Parallel HEV		
Powertrain Components		Energy(kWh)
CI-Engine	Fuel Input Energy	9.97
E-Motor	Regeneration Input Energy	9.98
Battery	Input Energy	9.98
	Output Energy	10.6
	Consumption Energy	0.62

6 Conclusions

This paper presented the simulation results using the Powertrain Energy Estimator (PEE) approach for two types of HEV's configuration; the series and parallel modes operation using FTP (EPA75) driving cycle. The applications cover two different vehicles platform models for simulation and performance analysis.

References

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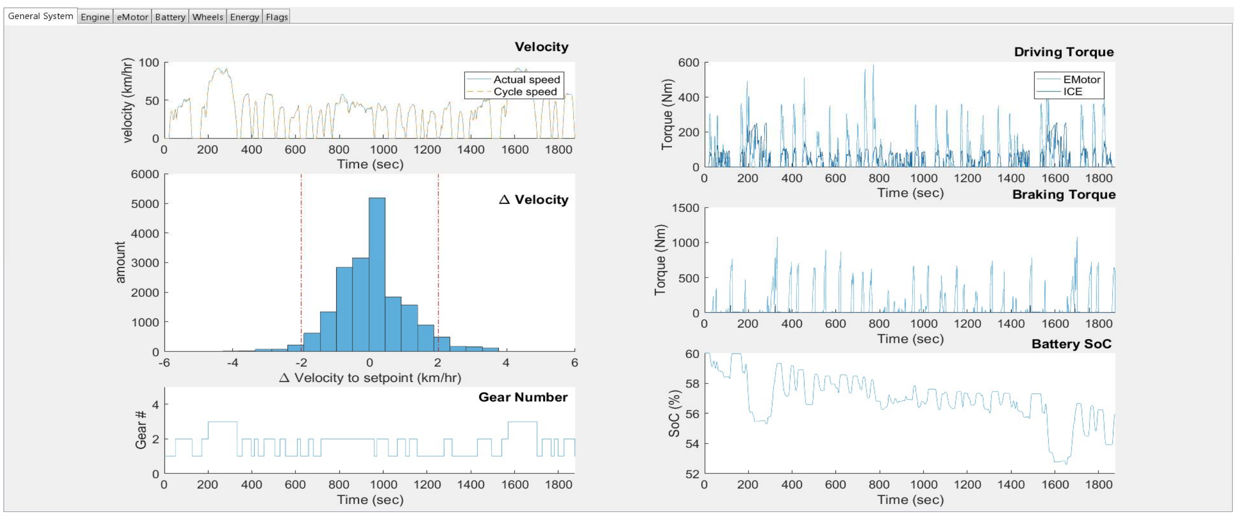

Figure13. General vehicle performance

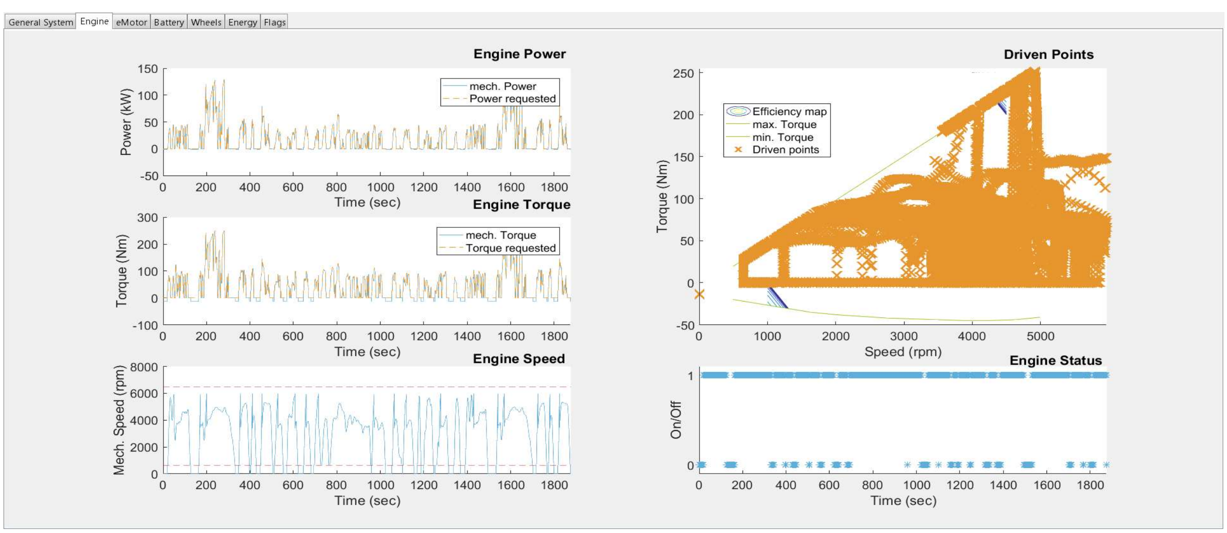

Figure14. Engine performance

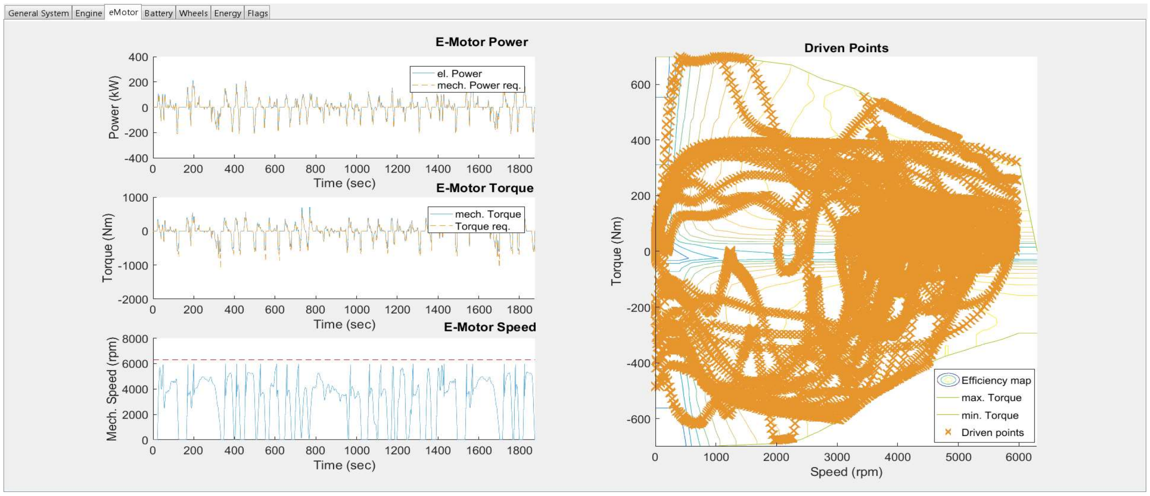

Figure15. Motor performance

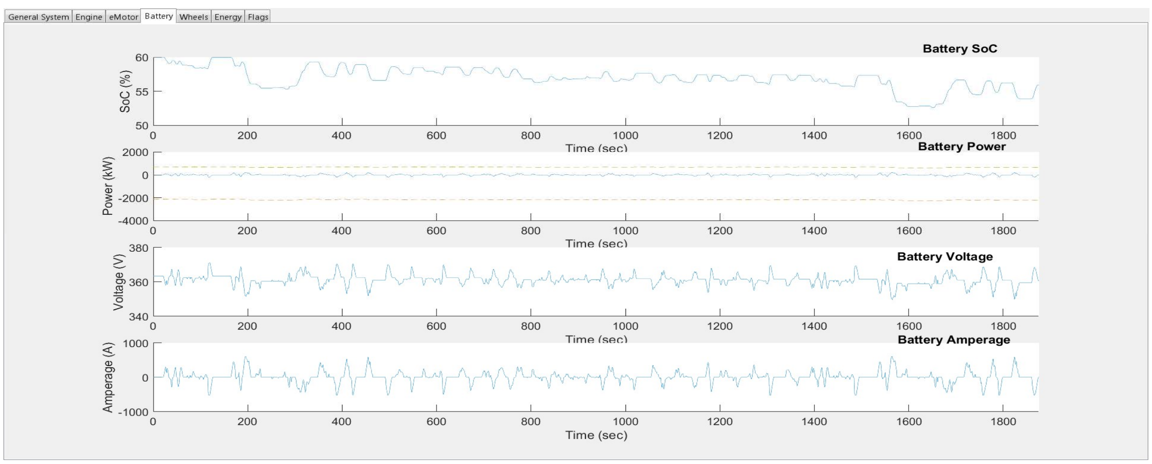

Figure16. Battery performance

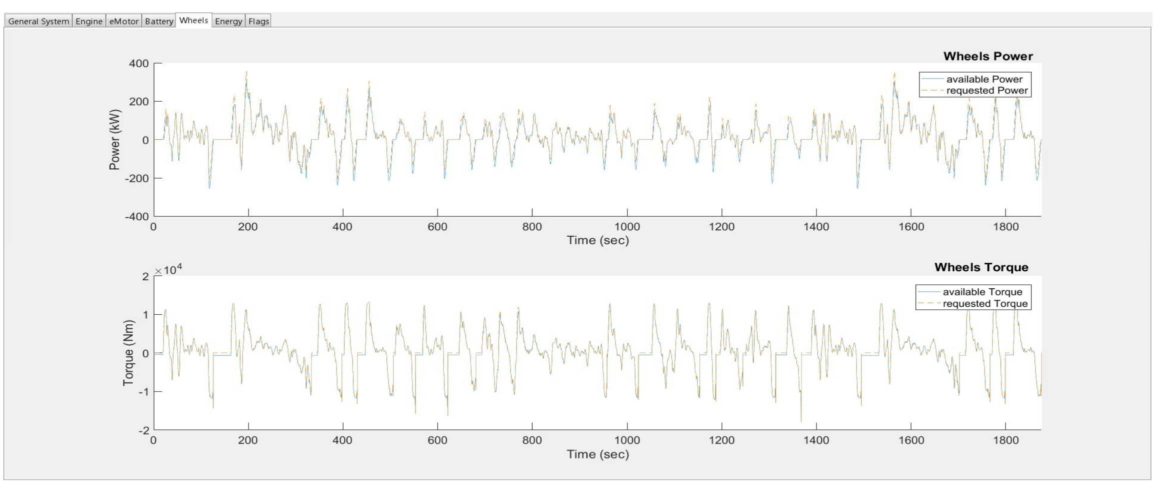

Figure17. Wheels performance

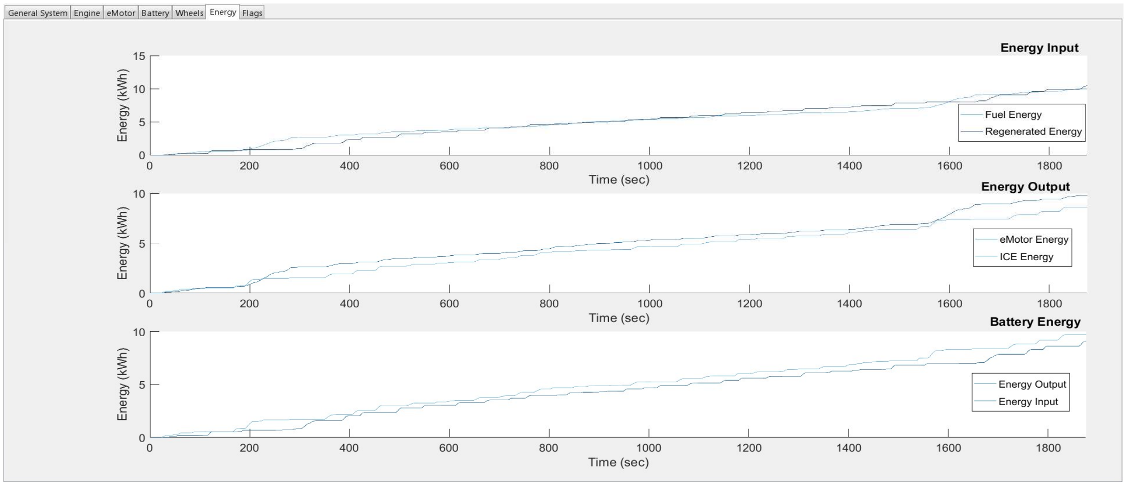

Figure18. Energy performance

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