PHEV control benchmark

Benchmark of control strategies for a Plug-in Hybrid Electric Vehicle

1 Introduction

This special benchmark session will consist in the comparison of several control strategies for a PHEV, implemented online on a simulator provided by the organizers.

All teams interested in participation to this benchmark will be provided with a fully functional simulator of a plug-in hybrid electric vehicle, and will implement a supervisory control strategy to optimize the vehicle fuel consumption. They will be required to submit their control strategies in the form of a Simulink block with a specific format (inputs/outputs/solver). All entries will be accompanied by a presentation and document describing them, and will be tested and evaluated during the special benchmark session scheduled at E-Cosm 2012.

The simulator (see Section 3) is a quasi-static simulator that accounts for longitudinal vehicle dynamics and battery SOC dynamics, while the engine and electric machines are modeled using stationary maps.

The strategies will be tested using two realistic driving cycles. The battery is completely charged at the beginning of the cycle and a complete recharge is assumed to take place at the end.

The participants will be able to make use of some information about the cycle, namely the (approximate) total distance and average speed, which could be easily retrieved from a GPS device (this information will be included in the simulator).

The evaluation of the strategies will be done on the basis of the fuel and energy consumption for the two cycles, as well as acceleration performance and controller runtime performance. The scoring is detailed in Section 4.

2 Signing up and submission

The teams interested in submitting an entry for the benchmark should contact us at ecosm12_benchmark@ifpen.fr to sign up. **You can start signing up immediately**. We will send you the simulator to develop your controller by the end of November 2011.

We will keep accepting inscriptions until February 15, 2012. Requests arriving later will not be taken into consideration. Obviously, the earlier you sign up, the more time you will have to work on your control strategy.

Deadline for submitting your entry is June 30, 2012. The entry will consist of the Simulink files with the controller and a document outlining the control strategy. The document can be **either**:

- *a short report* (< 3 pages), sent directly to the benchmark organizers, that will not be published in the conference proceedings; **or**

- a *regular paper*, that will be peer-reviewed and published in the conference proceedings if accepted. You can opt for this type of submission if you feel your control strategy is especially innovative. A special category, with deadline June 30, 2012, has been defined in IFAC Papercept to accommodate for it.

In addition to the document, we will ask you to prepare a brief presentation to introduce your work during the benchmark session.

At any time, feel free to contact ecosm12_benchmark@ifpen.fr for any inquiry or comment regarding the organization or the simulator.

3 Simulator

The quasi-static simulator provided implements a model of Chevrolet Volt, obtained using GM published data [1, 2, 3, 4]. The simulator implements three main blocks:

Driving cycle, which computes the torque demand based on the specified driving cycle, and also outputs the preview information (nominal distance and average speed between the current position and the end of the trip)

Control strategy, which is empty, except for input and output ports (which must remain the same)

Vehicle model, which contains the quasi-static model of the powertrain and vehicle dynamics. The inputs and outputs must also remain the same.

The users have access to the content of the driving cycle or the vehicle model block, but they should not be modified. Only their respective outputs can be used for developing the control strategy, and **only the controller block will be submitted** at the end. However, feel free to send us any bug report or improvement request for the blocks we provided, so that we can improve them and share them with all the participants.

3.1 GM Voltec powertrain [1]

The powertrain architecture powering the Chevrolet Volt consists in a power-split, planetary-based system, named *Voltec* and shown in Figure 1. Three clutches (C1, C2, C3) allow connecting or disconnecting the internal combustion engine (ICE), the generator (GEN) and the main traction machine (MOT). Both electric machines can actually work in both motoring and generating mode, and for both of them the sign convention is that positive torque and positive electric power indicate motoring operation.

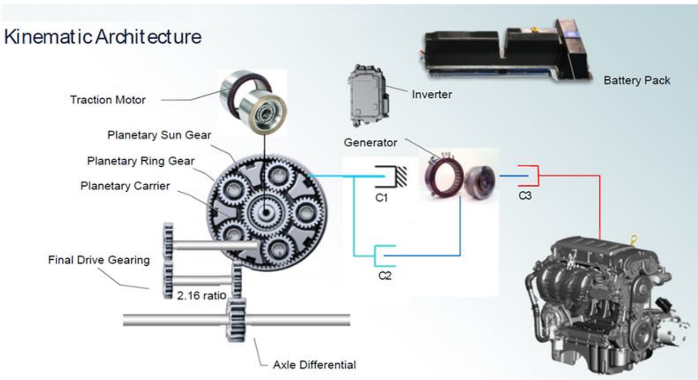

Figure 1: The Volt powertrain architecture as presented by GM [1]

The powertrain can operate in the following modes [1, 2, 3]:

1. *One-motor EV* (C1 locked, C2 open, C3 open, engine off). MOT alone propels the vehicle, powered by the battery. The planetary gear set introduces a fixed reduction between the machine MOT and rest of the driveline (final ratio and differential).

2. *Two-motor EV* (C1 open, C2 locked, C3 open, engine off). In this case, the machine GEN acts on the planetary ring through C2 and thus it changes the gear ratio between MOT and the powertrain output. This mode is useful to reduce MOT speed at high vehicle speed, thus increasing overall powertrain efficiency by combining the use of both electric machines.

3. *Range-extender mode* (C1 locked, C2 open, C3 locked, engine on). This is a traditional series-HEV mode: the engine and generator are connected and produce electric power; MOT alone propels the wheels.

4. *Power-split mode* (C1 open, C2 locked, C3 locked, engine on). In this mode, the three machines are all connected together with a variable speed ratio that depends on the generator speed. The mode allows transmitting mechanical power directly from the engine to the wheels, thus resulting in overall higher efficiency than a pure series mode.

3.1.1 Planetary gear set

The generator is connected to the ring (r), the motor is connected to the sun (s) and the transmission output is the satellite carrier (c). That is:

$$T_s = T_{MOT}$$

$$T_r = T_{GEN} + R_n T_{ENG}$$

The kinematic relation between the speeds of three components is:

$$\rho \cdot \omega_r + \omega_s = \omega_c(\rho + 1)$$

where ρ is the ratio between the number of teeth of the ring and the sun gear:

$$\rho = \frac{N_r}{N_s} = \frac{83}{37} = 2.24$$

The torque relations imposed by the planetary gear set are

$$\frac{T_r}{\rho} = \frac{T_c}{\rho + 1} = T_s$$

and the final gear ratio $R_d = 2.16$ is such that the torque at the wheel is

$$T_{wh} = R_d \cdot T_c.$$

The simulator is implemented using these relations, and neglecting the dynamics of the machines and the inertia of the gears.

3.1.2 Engine and electric machines

Since a quasi-static modelling approach is used, the engine and electric machines are represented by their efficiency maps, reported in Figure 2, Figure 3 and Figure 4.

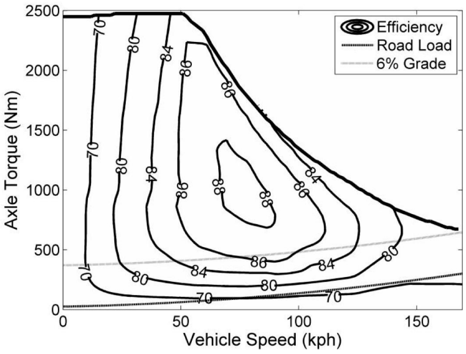

Figure 2: Efficiency Map of the electric motor (reported at the wheels, in 1-motor EV mode) [2]

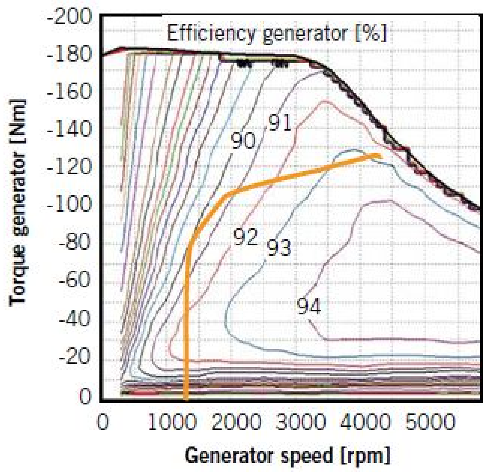

Figure 3: Efficiency Map of the generator with Optimal Operation Line of the VolTec [1]

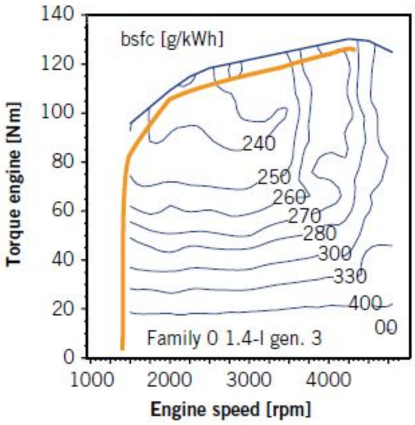

Figure 4: Specific fuel consumption lines of the EcoTec engine with its Optimal Operation Line [1]

3.1.3 Battery

The battery model implemented is based on a simple circuit model composed of a voltage source and a resistance, both functions of the battery state of charge (SOC). In the case of the Volt, only the basic battery parameters are published, and collected in Table 1. For the lack of specific data, the internal resistance and the open circuit voltage characteristic of a single Li-Ion cell are taken from generic data.

Table 1: Battery parameters

parameter	*value*	*source*
Total energy capacity	16 kWh	[1]
Total nominal voltage	360 V	[1]
SOC range	65%	[1]
Number of cells in series	96	[6]
Number of strings in parallel	3	[6]
Peak current	400 A	[6]

3.1.4 Vehicle parameters

The vehicle parameters are listed in Table 2. All simulations are carried out by considering the Volt with two passengers and a luggage of 60 kg, i.e. an additional weight of 220 kg with respect to the curb weight.

Table 2: Vehicle parameters [1]

VEHICLE TYPE	5-door, front-wheel-drive hatchback
CATEGORY	Electric vehicle with extended range capability
CHASSIS	Independent McPherson struts front Compound crank torsion-beam axle rear Four-wheel disc brakes Full regenerative brakes Electric power-assist steering
SEATING CAPACITY	4
CURB WEIGHT [KG]	1715 kg
OVERALL LENGTH [MM]	4498
WHEELBASE [MM]	2685
WIDTH [MM]	1798
HEIGHT [MM]	1430
CARGO VOLUME [L]	301
BATTERY	T-shaped module with integrated thermal management Lithium-ion manganese-spinel (LiMn204)
TOTAL RATED ENERGY [KWH]	16
TOTAL USABLE ENERGY [%]	65
RECHARGE TIME	< 4 h @ 230 V / 16 A
FUEL TANK [L]	35.2
POWER [KW / HP]	111 / 150
TORQUE [NM]	370
TOP SPEED [KM/H]	161
ACCELERATION (0 TO 100 KM/H) [S]	9
EV RANGE [KM]	40 – 80 (MVEG cycle)
TOTAL RANGE [KM]	> 500

3.1.5 Data files

All data mentioned, as well as other additional details needed to run the simulation, is contained in the file `Volt_data.mat` provided with the simulator, together with a document detailing its content.

4 Benchmarking

Each entry will be evaluated according to several metrics, listed in Table 3 with their respective weight. The weighted sum of the results will provide the overall score. All scores are best when minimized. The actual scoring is obtained by normalizing the result obtained in each metric with respect to the average value for that metric.

Table 3: Scoring metrics

	Metric	Weight
Performance (30%)	Acceleration 0-100 km/h [s]	7.5 %
	Acceleration 70-120 km/h [s]	7.5 %
	Acceleration 0-1000 m on 4% slope [s]	7.5 %
	Braking distance from 100 km/h [m]	7.5 %
Energy and economy (50%)	Energy Consumption [MJ]	15 %
	Petroleum Energy Use [MJ]	20 %
	Tailpipe Emissions (not modeled)	0 %
	Well-to-wheel CO2 Emissions [kg]	15 %
Computational performance (20%)	Processor use [%]	10 %
	Memory use [MB]	10 %

Notes on the scores:

Energy and economy: Total for two different driving cycles, based on real-world data, length over 60 km each

Data for CO2 emissions: Europe average (results for France, US, and China will be provided for information)

Computational Performance: monitoring of resource use on the computer

Example of scoring:

Assume that there are 4 teams, whose scores in the 0-100 km/h acceleration test are respectively:

9.1 9.5 10.0 8.5 s.

The average is 9.275 s and the normalized scores are

0.9811 1.0243 1.0782 0.9164,

which are then multiplied by 0.075 (the weight of the test reported in Table 3) and summed to the other results in order to obtain the overall score. The lowest score will be the best.

5 References

[1] Q. Falières et al., *A Contradictory Analysis of GM Voltec powertrain*, European Electric Vehicle Conference (EEVC), 2011

[2] U. D. Grebe and L. T. Nitz, *VOLTEC – The propulsion system for Chevrolet Volt and Opel Ampera,* ATZ autotechnology, 02/2011

[3] R. Parrish et al., *Voltec Battery Design and Manufacturing*, SAE Paper 2011-01-1360, 2011.

[4] M. A. Miller, A. G. Holmes, B. M. Conlon and P. J. Savagian, *The GM Voltec 4ET50 Multi-Mode Electric Transaxle*, SAE Paper 2011-01-0887, 2011