IEEE VTS Motor Vehicles Challenge 2018 – Energy Management of a Range Extender Electric Vehicle

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***Abstract* — In October 2016, a first international challenge devoted to the energy management of a fuel cell/battery vehicle was launched during the 2016 IEEE Vehicle Power and Propulsion Conference (VPPC), in Hangzhou, China. Following the success of this first initiative, this paper describes the technical framework of a second challenge focused on the energy management of a Range Extender Electric Vehicle, the Chevrolet Volt. Both Academic and Professional teams are welcomed to participate in this challenge. The aim is to develop a robust Energy Management Strategy to minimize the fuel consumption and the battery charging cost. In this way, a validated vehicle model and control will be provided to the challenge participants by the use of the Autonomie Matlab Simulink & Stateflow™ based software, developed by the Argonne National Laboratory. The top scoring participants will be distinguished and invited to present their results in a special session at the 2018 IEEE VPPC.**

Keywords — Energy management, hybrid vehicle, range extender, Voltec

I. INTRODUCTION

An international challenge devoted to the energy management of a fuel cell/battery vehicle was launched in October *2016* during the *2016* IEEE VPPC, in Hangzhou, China [1]. *48* academic, student and professional participants from *14* different countries took part in the aforementioned challenge. It has rewarded the best energy management strategies of a fuel cell/battery vehicle. This year, the IEEE Vehicular Technology Society, the University of Quebec in Trois-Rivières, Argonne National Laboratory, FCLAB Research federation, FEMTO-ST Institute, University of Lille and MEGEVH (French scientific network on HEVs) launch the 2nd IEEE VTS Motor Vehicles Challenge *2018*. This challenge focuses on the energy management of a Range Extender Electric Vehicle (RE-EV). Both Academic (from University or College) and Professional teams are welcomed to participate. The top scoring participants will be distinguished and invited to present their results in a special session at the *2018* IEEE VPPC.

Development of Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) is an important challenge to reduce local greenhouse gas emissions and petroleum-based fuel dependency issues of combustion engine vehicles [2]. HEVs combine the benefits of multiple sources to meet different goals, such as reducing the fuel consumption [3], [4]. Nevertheless, the Energy Management Strategy (EMS) appears as a critical issue for HEVs [5]-[10]. Indeed, the EMS determines which component has to be operated according to a mission profile and technical specifications. The study of the *2012* Chevrolet Volt commercial vehicle, and more especially the Voltec system Gen *1* architecture, is proposed for this challenge (Fig. 1). An Internal Combustion Engine (ICE) and two electric machines supplied by a battery pack provide the power to the transmission system.

Split the vehicle traction power between the ICE and the electric machines allows to operate in a full EV, series or parallel hybrid modes. Regenerative braking and, potentially, fuel consumption reduction can be obtain by operating the ICE into it best fuel efficient zone [2]. Depending on the driving cycle and environmental conditions, the Voltec Li-ion battery allows to drive *40* to *80* km in EV mode. The total vehicle range is about *610* km with a maximal speed up electronically limited to *161* km/h [11]. Compared to EVs, combined gasoline and a Li-ion battery trough an electrified powertrain allows long driving range with short refueling times. However, the battery cycle life is an important characteristic of RE-EV. In recent years, batteries made significant progress. While a cycle life of *1 000* can be expected for common Li-ion batteries [12], the *2012* Chevrolet Volt Li-ion module can perform *3 000* to *5 000* cycles due to the use of a liquid-based thermal management system [11], [13]. General Motors (GM) then warrants the Chevrolet Volt batteries for *8* years, or *160,000* km (*100 000* miles). Experimental tests from the Idaho National Laboratory (INL) of the United States Department of Energy on four Chevrolet Volt confirm the GM guarantees [14]. Assuming a linear interpolation, the tests indicate that a Volt can expect to travel around *600 000* km before its battery end of life, characterized by a battery capacity reduction of *30* %

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(Fig. 2) [12], [15]. For these reasons, the battery degradation cost is not taking into account in this challenge.

In the framework of this challenge, the complete validated vehicle model and its associated local control are provided through Autonomie software of the Argonne National Laboratory. Autonomie is a simulation tool for vehicle energy consumption and performance analysis. Developed in collaboration with GM, it is a Matlab™-based software environment and framework for automotive control-system design, simulation, and analysis [17]. Through the proposed challenge, participants will have to design the Voltec energy management strategy using Autonomie.

The aim of this challenge is then to develop a robust Energy Management Strategy to:

- Minimize the fuel (gas) consumption,
- Optimize the use of the battery.

In section II, the studied RE-EV is presented. The architecture of the vehicle model, control and strategy are depicted in section III. The energy management design specifications, the scoring procedure and the proposed Autonomie Matlab Simulink & Stateflow™ based software description are finally described in section IV.

II. Studied Range Extender Electric Vehicle

The studied vehicle is the *2012* GM Chevrolet Volt and the Voltec Gen *1* system. This is a range extender electric vehicle equipped with two electric motors (EM_1 and EM_2), an Internal Combustion Engine (ICE), a Li-ion battery, a reduction gear transmission, two driven-wheels and a Planetary Gear (PG) to split the traction power [11], [18] (Fig. 3). Note that the version of the proposed vehicle is close to the *2012* Chevrolet Volt (same configuration and control), but the dimensioning of the components is slightly different (Table 1).

The ICE and the electric motor EM_2 are connected through a clutch CL_1. EM_2 is connected to the PG ring gear through a clutch CL_2. The electric motor EM_1 is directly connected to the PG sun gear. The PG carrier is finally connected to the reduction gear. During a trip, the management of the two clutches (CL_1 and CL_2) and one brake (BK_1) allow four traction operation modes:

1) ***Mode 1: One-motor EV (EV_1).*** CL_1 and CL_2 are open, and BK_1 is closed. The electric motor EM_1 propels the vehicle.

2) ***Mode 2: Two-motors EV (EV_2).*** CL_1 and BK_1 are open, and CL_2 is closed. EM_1 and EM_2 operate on the PG to propel the vehicle.

3) ***Mode 3: Series.*** CL_1 and BK_1 are closed, CL_2 is open. The electric motor EM_2, driven by the ICE, charges the battery which supplies the electric motor EM_1.

4) ***Mode 4: Power split (Output split).*** CL_1 and CL_2 are closed, BK_1 is open. ICE, EM_1 and EM_2 power are combined to propel the vehicle.

Fig. 1 Reference *2012* GM Volt Range Extender Electric Vehicle

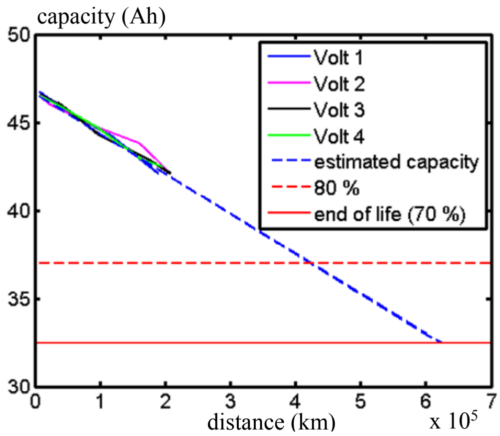

Fig. 2 *2012* GM Chevrolet Volt battery capacity test plotted from the INL experimental data [14]

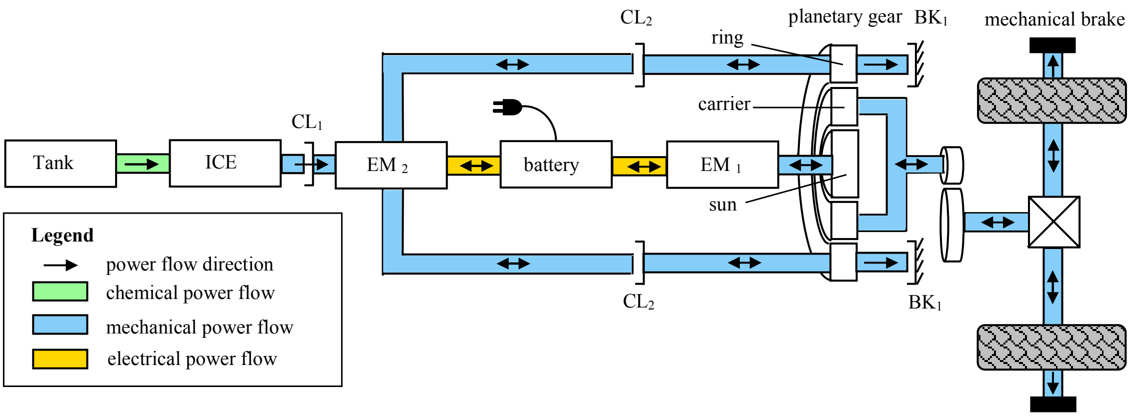

Fig. 3. Voltec system architecture

Finally, while the vehicle is parked, the battery can be charge from an OnBoard Charger Module (OBCM) which can be connected to the electric grid.

TABLE 1 STUDIED CHEVROLET VOLT PARAMETERS

ICE Engine	1.8 L, 73 kW
EM_1 peak power	70 kW
EM_2 peak power	50 kW
Battery	11 kWh
Vehicle mass	1126 kg
PG ratio (Z_s:Z_r)*	37:83
Final drive ratio	3.02
Whell radius	0,3 m

*Z_s and Z_r are the number of sun gear and ring gear teeth, respectively [19].

III. VEHICLE MODELING AND CONTROL

A. Model and local control

All the studied vehicle model and control components have been validated in the Argonne National Laboratory. Standards tests have been used to test and collect data from the vehicle on dynamometer or close test procedures [19] (Fig. 1). For example, the experimental measurement ICE efficiency and fuel consumption maps are plotted in function of torque and rotational speed in Fig. 4 and Fig. 5, respectively. From this models, the ICE torque can be directly controlled through a dedicated controller. The model and control of all the components of the studied RE-EV are included in the Autonomie software [17], developed by Argonne National Laboratory, and available for this challenge (see §IV.B).

B. Energy Management Strategy

The Voltec Gen *1* system represents a complex system. Its control can be organized in two parts: the local control and the Energy Management Strategy (Fig. 6). The local control acts as close as possible to the system elements to bring it to set points (light blue blocks in Fig. 6). The EMS translates the driver requirements and coordinates the local control according to specifications (dark blue block in Fig. 6). The vehicle performances are then dependent on target objectives, for example a reduction in fuel consumption. Thus, the EMS appears as a key element in the operation of hybrid vehicles such as the studied RE-EV. In this way, well designed EMS may lead to reduce the trip cost while ill-designed EMS may lead to higher fuel consumption than a conventional ICE vehicle for example.

From strategy inputs to be defined by participants (e.g. the battery state of charge or the vehicle velocity), the EMS can act on the clutch CL_1, CL_2 or the brake BK_1, to select the traction operating mode. Depending on the selected mode, the EMS must specify the ICE, the EM_1 and EM_2 torque references to reach specifications. *7* strategy-level outputs need to be defined by the participants to manage the vehicle: the CL_1, CL_2 and BK_1 states to select the operating mode, the torques $T_{ICE\text{-}ref}$, $T_{EM1\text{-}ref}$ and $T_{EM2\text{-}ref}$ and the ICE rotation speed demand $\Omega_{ICE\text{-}ref}$. Notes that the braking strategy will not be considered in the purpose of this challenge.

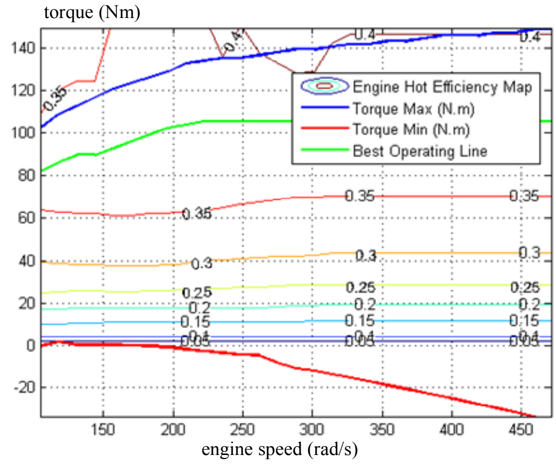

Fig. 4. ICE efficiency map

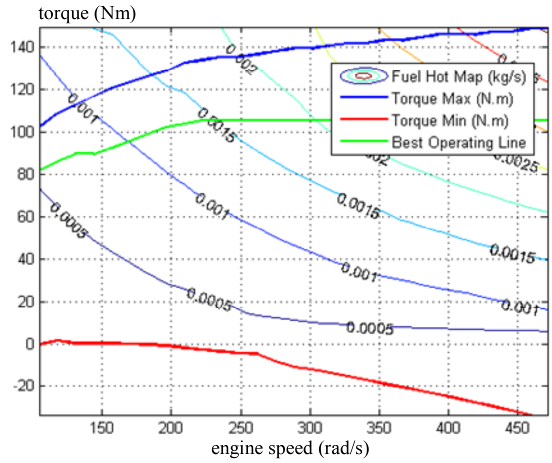

Fig. 5. ICE fuel consumption map

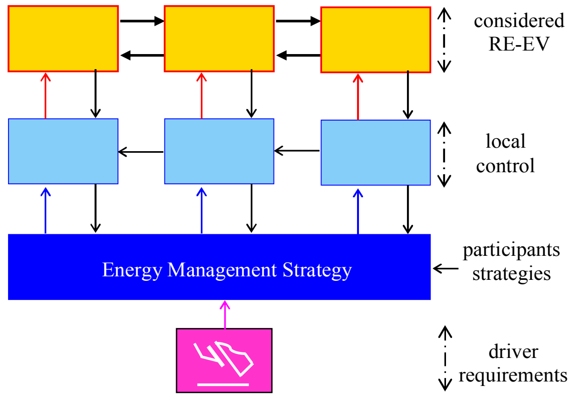

Fig. 6. Considered RE-EV management

IV. ENERGY MANAGEMENT STRATEGY DESIGN

A. Specification and Scoring

The traction subsystem will impose the battery current depending on the driver requirements, the considered operating mode, the vehicle characteristics and the corresponding control. Then, the energetic performances of the studied RE-EV will depend on the developed energy management strategy. In this way, the participants of this challenge must develop a robust EMS to:

1) ***Minimize the fuel consumption.*** The fuel mass flow (or the gas mass flow) is function of the ICE torque and rotation speed (Fig. 5). The gas trip cost can be calculated considering the total gas consumption:

$$\$_{gas} = \int_0^t \dot{m}_{gas} dt gas_{\text{cost}} \quad (1)$$

with $gas_{cost}=0.795$ US \$/kg based on the *2016* U.S. Energy Information Administration (EIA) [20].

2) ***Optimize the use of the battery.*** Depending on the battery State of Charge (SoC) of the final trip, a battery charge penalty will be set up. In this way, at the end of a driving cycle, the scoring step will automatically full charged the battery by connecting it to the electric grid using the OBCM and a level 2 home charging station at *230* V/*16* A. The charge cost $\$_{charge}$ depends on the final battery SoC and the electricity price (Fig. 7). Therefore, the United States *2016* average electricity cost was *0.137* US \$/kWh [21]. The cost of this recharge step penalty $\$_{charge}$ is then taking into account for the global cost function definition $\$_{global}$:

$$\$_{global} = \$_{gas} + \$_{charge} \quad (2)$$

The participant developed EMSs will be scored according to the known scoring equation $\$_{global}$ (2) with an unknown driving cycle including urban and extra urban driving. The aim of the challenge is to propose real-time strategies: the knowledge of the scoring driving cycle is not known beforehand and off-line optimization cannot be included into the final EMS.

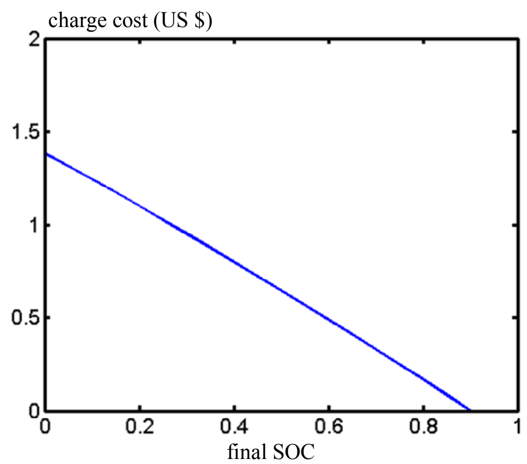

Fig. 7 Battery charging cost $\$_{charge}$

B. Autonomie Simulation Software

In order to develop and test their strategies, participants will be provided with the Autonomie simulation program downloadable from the Argonne website [17]. Autonomie is a Matlab Simulink & Stateflow™ based software environment and framework for automotive powertrain and control system design, simulation and analysis. This includes a graphical interface and uses Matlab Simulink& Stateflow™ for simulation.

From the Autonomie Graphical User Interface (GUI), the user can first set up the vehicle model and run tens different international standard driving cycles (e.g. Urban Driving Cycle (UDC) or Worldwide harmonized Light vehicles Test Procedure (WLTC) driving cycle) and test procedures. In the purpose of this challenge, a special version of Autonomie will be provided. This retains the standard driving cycles and includes the *2012* Chevrolet Volt powertrain configuration, composed of the driver model, a limited Vehicle Propulsion Controller (VPC, the participant EMS strategies to be develop) and the traction system which is composed of the considered RE-EV models and local controls. In Autonomie, the powertrain models and controls are organized based on a hierarchical architecture as presented in Fig. 8.

After the first setup of the vehicle from the Autonomie GUI, the model can be re-used directly from Matlab™ via the following procedure. Five working steps can then be defined to develop the participant EMSs:

1) ***Initializing the model in Matlab™.*** Once the setup process is completed, the simulation program can be run using Matlab Simulink & Stateflow™. Notes that all the component parameter, models, or initialization files are available from Autonomie,

2) ***Modifying the VPC block*** by replacing the example strategies which are already in the VPC block. Notes that participants must not modify the model and local control part of the simulation program,

3) ***Running the model*** by clicking on the play button on the Simulink menu or by running the command sim(gcs),

4) ***Computing and saving the results.*** Once the simulation has been run, participants will need to also launch the Autonomie post processing script to compute the component powers, energies, efficiencies, fuel & electrical consumption,

5) ***Analyzing the results*** using the Autonomie data analysis interface (Fig. 9).

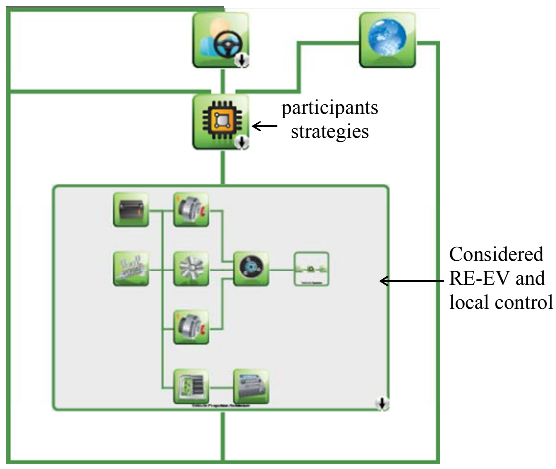

Fig. 8. Autonomie vehicle navigation

C. Participation procedure and award

Participants are invited to join in with this challenge by following the participation procedure describes in the IEEE VTS Challenge website [22]:

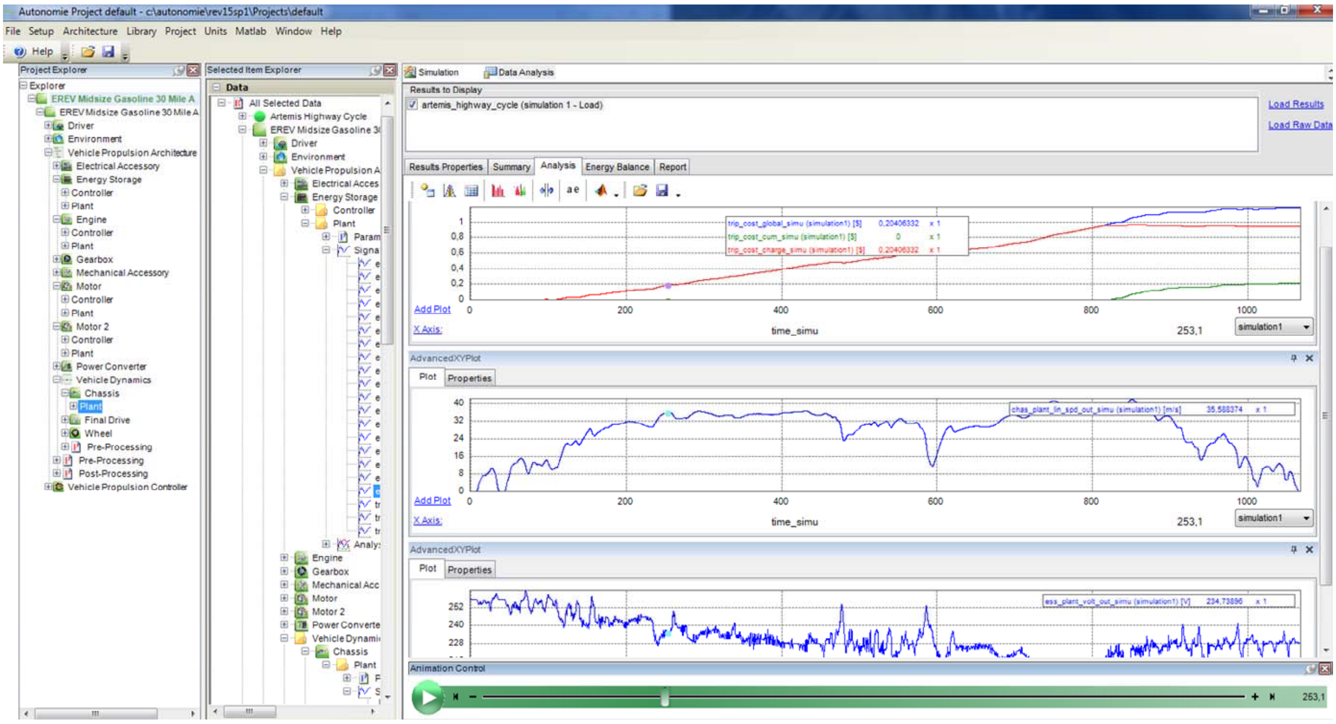

Fig. 9. Autonomie user interface (data analysis)

http://www.uqtr.ca/VTSMotorVehiclesChallenge18

Teams that developed the best EMS will received an award that consisted of: a certificate, an invitation to write and present a paper for the VPPC conference in *2018*, and a grant that will cover the expenses related to the participation and attendance to VPPC *2018* (conference registration, transport, accommodation).

V. CONCLUSION

In order to reach the best performances of the studied *2012* Chevrolet Volt, an energy management strategy has to manage the power split between the engine and two electric motors. The aim of this challenge is to design this strategy and to integrate it in a simulation software. The objective is to develop a robust energy management strategy to minimize the fuel consumption and to optimize the use of the battery. In this way, participants shall be ranked on the basis of a cost function which takes into account the fuel consumption and the battery final charge, with an unknown scoring driving cycle including urban and extra urban driving. The proposed challenge can then promote the realization of future innovative energy management techniques.

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