

## DEVELOPMENT A MODEL OF HARDWARE-IN-THE-LOOP SIMULATOR OF ELECTRIC VEHICLE

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**Abstract-** This paper presents a simulator of a Hybrid Energy Storage System (HESS), using the Macroscopic Energy Representation (MER). The simulator is developed for electric automotive applications, powered by various energy sources. The Fuel Cell (FC) and/or battery are used as primary sources, the Supercapacitors (SC) and/or battery are secondary sources. The simulator allows to evaluate the energy management between different sources in order to optimize the energy use and increase the autonomy of the main source. The developed simulator has been implemented and validated under Matlab/Simulink.

**Keywords:** Electric Vehicle, Energetic Macroscopic Representation, Hardware-in-the-Loop, Multi-Physics' Modelling.

### 1. INTRODUCTION

Nowadays, with the purpose of reducing fuel consumption and exhaust emissions related to means of transport, electric vehicles (EV) and hybrid electric vehicles represent one of the most efficient solutions. These technologies are based on multisource electric systems, which use fuel cells and/or batteries as a primary source [1], SCs and/or batteries as a secondary source. Moreover, in order to enhance the performance of the main source, power management strategies are used, in order to increase the main source reliability [2] and [3]. However, before applying a new strategy on a real

vehicle, the development and validation has to be performed on simulators that allow to emulate the vehicle's real behavior [4-7]. Such as the software-in-the-loop (SIL) simulators that are built upon the dynamic model of the vehicle and the electrical sources [8] and [9].

The second type are the hardware-in-the-loop (HIL) simulators. In recent years, HIL simulation [10] has been a key tool for experimentation and validation of models and prototypes. HIL simulation consists in introducing a hardware part into a digital simulator, in order to validate the designed architecture, or to improve the simulation accuracy, through the introduction of real phenomena [11] and [12].

In this context, this paper proposes a HIL simulator of an EV scale model. Indeed, the developed HIL simulator is made of two coupled DC motors, the first one allows to simulate the vehicle applied loads, and the second one allows to simulate the vehicle propulsion motor.

### 2. HIL DEVELOPMENT

The developed HIL simulator is composed of two DC motors, the first motor is a generator that allows to emulate the vehicle mechanical characteristics, generating a resistive torque profile, identical to that produced by the vehicle mission profile. The second motor is a DC motor that represents the vehicle's propulsion motor [13] illustrated in Figure 1.

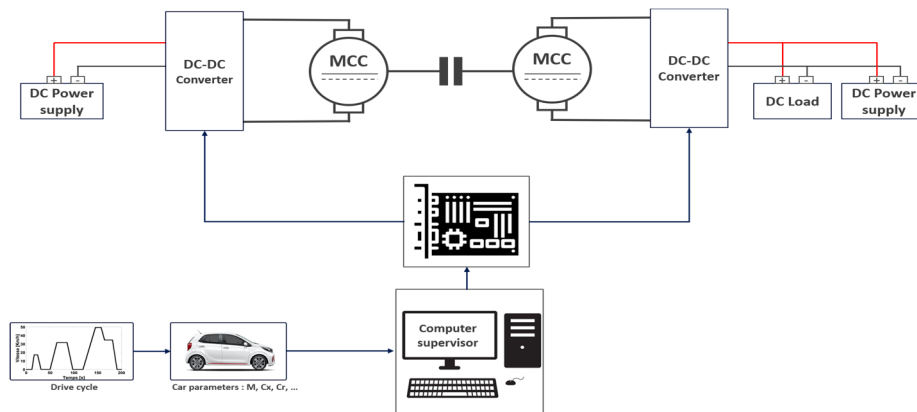


Figure 1. Synoptic scheme of the EV simulator

2.1. Vehicle Dynamic Emulator

The vehicle mechanical parts emulator, should, through an interface, generate a resistive torque  $T_r$ , equal to the torque generated at a given vehicle speed  $V$ . The emulator is represented by a direct current motor used as a generator; the motor torque resistive  $T_{res}$  will be adjusted via a servo structure [14]. The DC generator is represented using Equations (1)-(6). The EMR model of the generator is shown in Figure 2.

$$U_{mot} = mU_{mot} \tag{1}$$

$$I_{ch} = mI_{mot} \tag{2}$$

$$U_{mot} - E_{mot} = L \frac{dI_{mot}}{dt} + RI_{mot} \tag{3}$$

$$T_{mot} = kI_{mot} \tag{4}$$

$$V_{mot} = kE_{mot} \tag{5}$$

$$T_{mot} - T_{res} = J \frac{dV_{mot}}{dt} \tag{6}$$

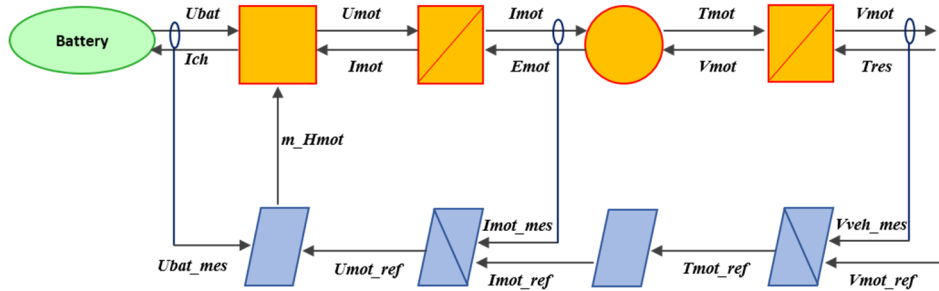


Figure 2. EMR and deduced control of DC motor/generator

Based on the fundamental principle of dynamics, the EV modelling is presented by the following direct dynamics Equation (7) [15]:

$$M \frac{dV}{dt} = F_{tr} - F_{res} \tag{7}$$

Vehicle studies have shown that resistance forces can be categorized into three distinct forces when the vehicle is traveling at a speed  $V$  in Equation (8):

- Rolling resistance forces is induced by the tire reaction on the road surface,
- The drag force produced by the air friction on the vehicle body,

- The force of gravity, related to the vehicle's mass and the road's inclination.

$$F_{res} = C_r Mg \cos \alpha + Mg \sin \alpha + \frac{1}{2} \rho S C_x V^2 \tag{8}$$

The resistive torque Equation (9) applied to the motor is then given by [16]:

$$T_{res} = \frac{R}{i} F_{res} \tag{9}$$

The dynamic vehicle emulator developed with the EMR technic, is presented in Figure 4.

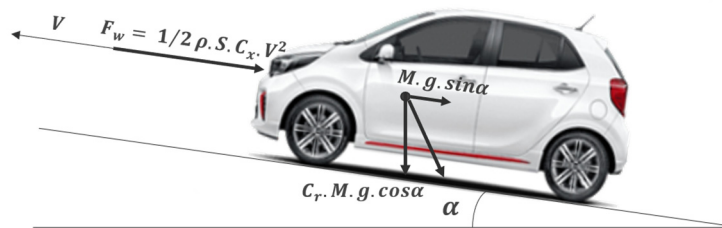


Figure 3. Schematic of resistance forces acting on moving vehicle

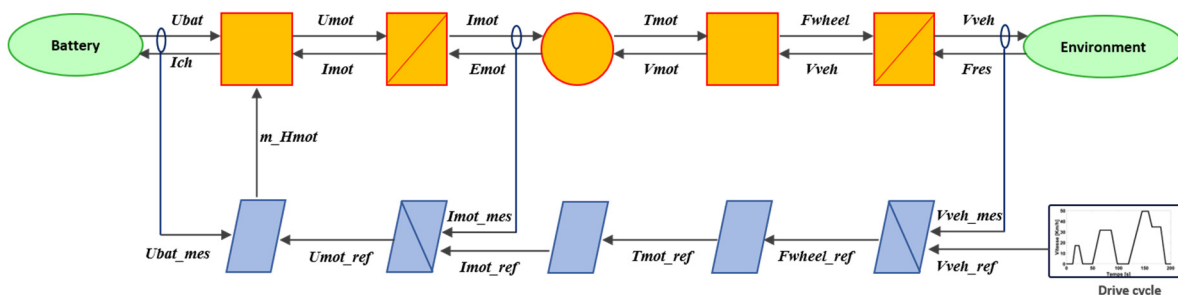


Figure 4. EMR and deduced control of the Vehicle Emulator

Table 1. The different characteristics of the reduced EV model

Variable	Designation	Value
$V$	Vehicle speed (m/s)	ECE-15 cycle
$M$	Vehicle mass	10 Kg
$g$	Gravitational constant	9.81 m/s <sup>2</sup>
$\alpha$	Road Grade	0 rad
$C_r$	Coefficient of rolling resistance	0.010
$C_x$	Aerodynamic coefficient	0.30
$\rho$	Air density	1.255 Kg/m <sup>3</sup>
$S$	Front surface	2.5×10 <sup>-4</sup> m <sup>2</sup>
$R$	Wheel radius	0.0203 m

### 2.2. Propulsion motor

The propulsor motor is represented by a DC motor powered by a DC-DC converter. The model of the HIL simulator with EMR is given in Figure 5.

### 3. RESULTS AND DISCUSSIONS

The HIL simulator of the vehicle, has been implemented in MATLAB-Simulink, using the EMR library developed at the University of Lille, France. The HIL simulator of the vehicle developed with the control layer, is presented in Figure 6.

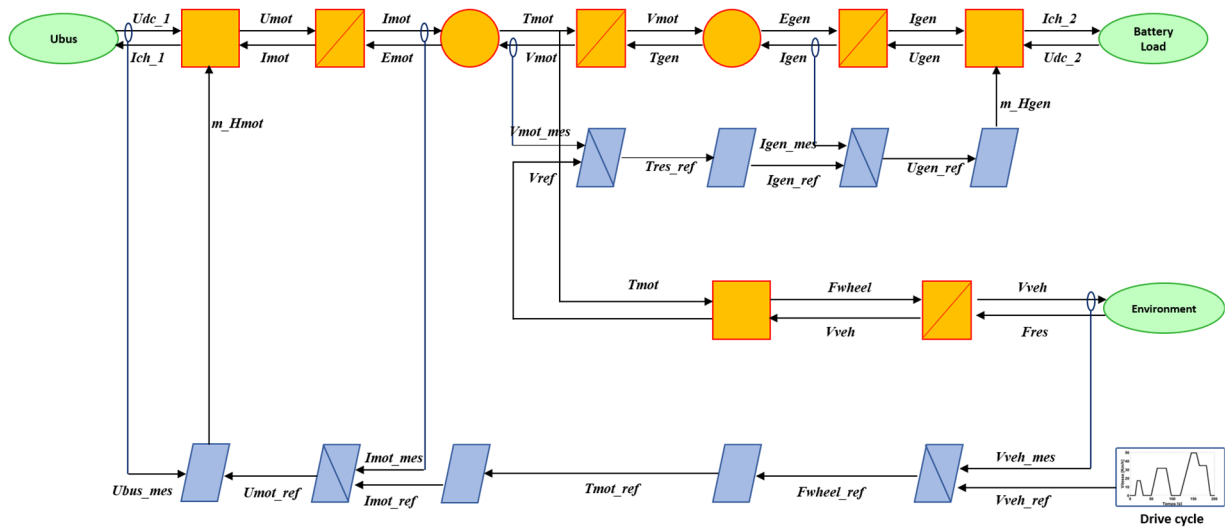


Figure 5. EMR and deduced control of the HIL simulator

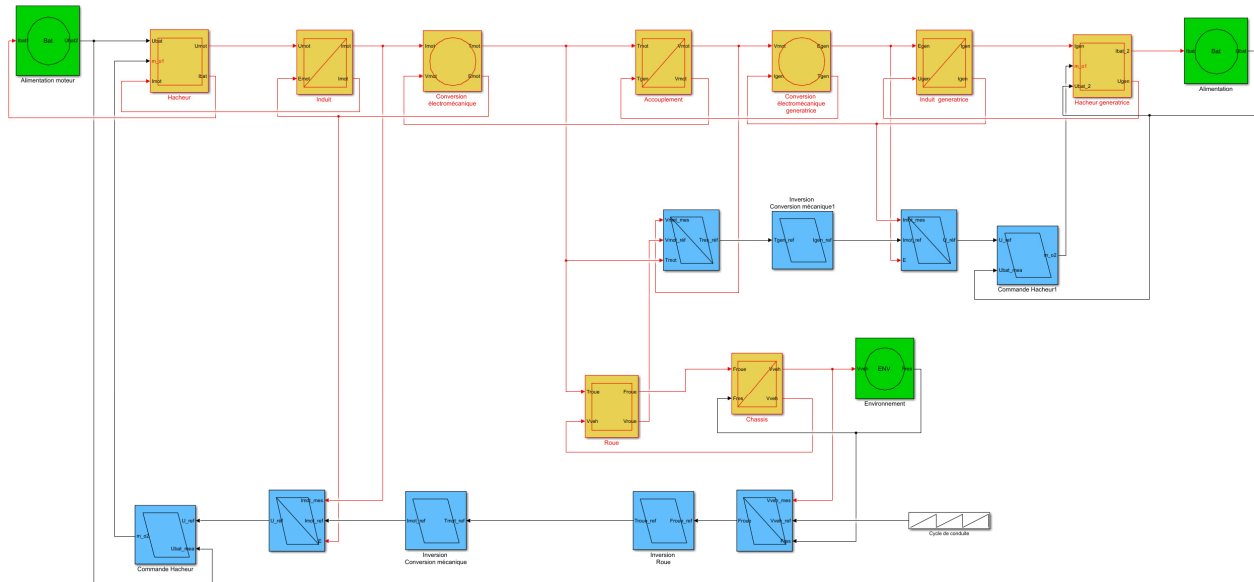


Figure 6. MATLAB-Simulink model of the studied HIL

In order to validate the efficiency of the developed EV simulator, simulation tests were performed. The simulation tests were carried out in the MATLAB/Simulink environment with a model of a typical electric vehicle, which use a motor power of 100 W and a voltage supply of 24 V, the vehicle parameters as shown in Table 1. The used driving cycle is ECE-15 urban driving cycle, of the European NEDC driving cycle [17], as shown in Figure 7.

The ECE-15 cycle takes 200s. Each cycle consists of a speed acceleration, a constant speed level and a constant deceleration. The Figure shows the acceleration of the ECE-15 cycle, where the power peaks can be noticed during the acceleration phases. In addition, the behavior of the EV provides the possibility of energy recovery during the deceleration phases, represented by negative power. This power can be used for sources charging in order to optimize the EV range.

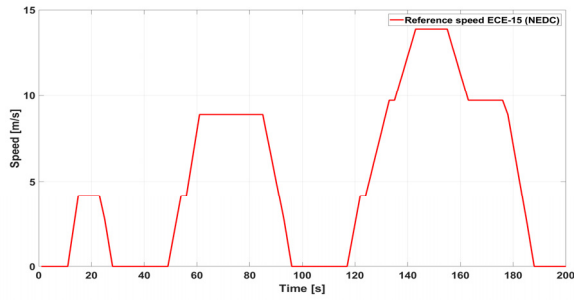


Figure 7. Speed of the ECE-15 cycle

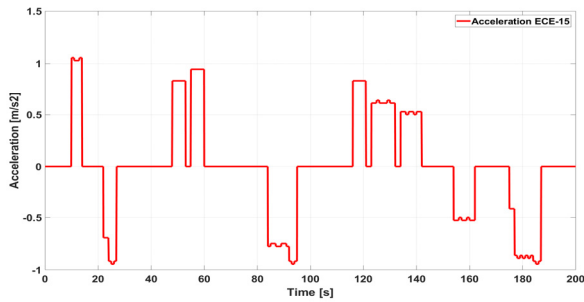


Figure 8. Acceleration of the ECE-15 cycle

Various results of the simulation can be analyzed, such as vehicle speed, torque and power of both engines. The Figure 9 shows that, the vehicle speed follows the reference during urban cycle. The Figure 10 shows the torque generated by the DC motor, used to overcome the resistive force of the generator, ensuring that the desired reference speed is respected.

A comparison of the torque and power profiles of the motor and the generator shown in Figures 11 and 12, demonstrates that when the vehicle accelerates during the driving cycle, the motor drives the generator, stopping the positive motor torque and negative generator torque. When the vehicle decelerates, the generator torque is positive while the motor torque is negative, which allows the current to be reinjected into the motor battery (regenerative braking).

The HIL simulator of the EV, was developed with EMR, and simulated using Matlab/Simulink, to evaluate the system behavior and the energy performance. One of the applications of HIL simulator, is to study the energy management between different sources. It can be used to compare different control strategies in a given cycle.

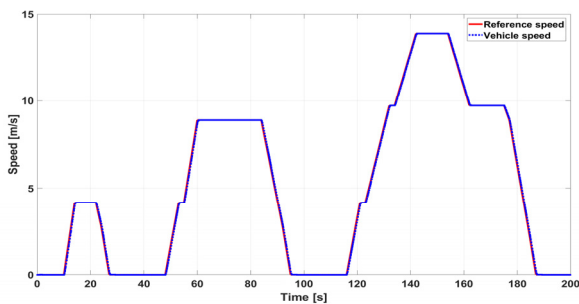


Figure 9. Simulation HIL speed

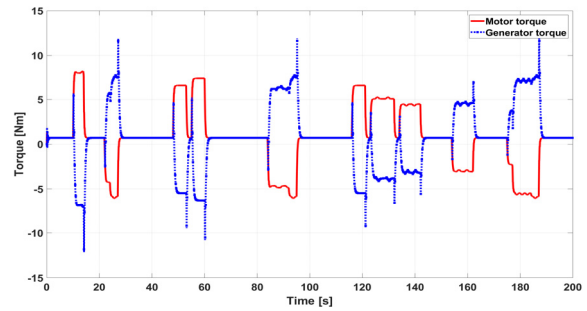


Figure 10. Simulation motor and generator torque

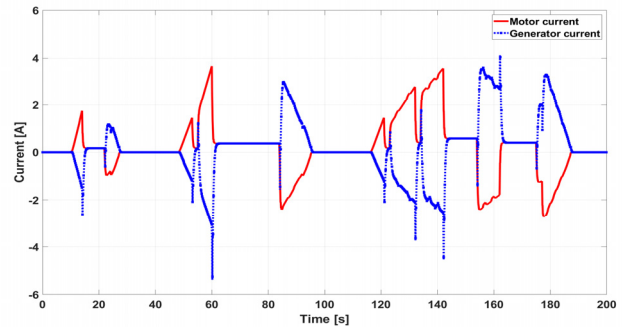


Figure 11. Simulation motor and generator current

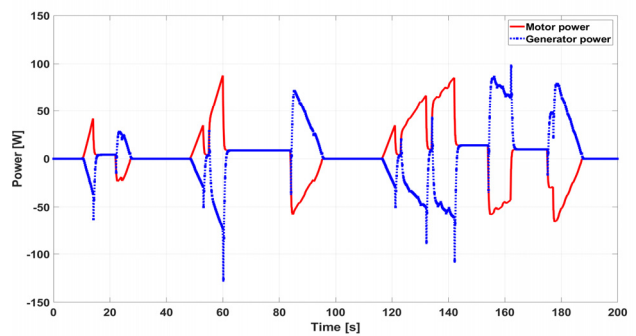


Figure 12. Simulation motor and generator power










## 6. CONCLUSIONS

This paper proposes a HIL simulator of an EV's scale model. This simulator uses two coupled DC motors. The first one represents an emulator of the EV mechanical part, while the second one represents the powertrain of the vehicle. This HIL simulator is developed with EMR approach under Matlab/Simulink, and has been validated with the NEDC cycle. Experimental results have shown that the developed HIL simulator is working successfully.

Finally, this work represents a first step in developing a HESS micro system, including a PEM fuel cell considered as primary source and a battery/SC used as secondary source. The objective of this simulator is to design an efficient energy distribution strategy between the sources (EMS) and to examine its reliability, so that it can be used in a real vehicle.VE.

APPENDIX

Synoptic of Energetic Macroscopic Representation (EMR)

		
Source element (energy source)	Mono-physical conversion (without energy storage)	Accumulation element (energy storage)
		
Coupling element (energy distribution)	Multi-physical conversion (without energy storage)	Control block with a controller (close-loop)
		
Inversion of coupling element	Control block without controller	Strategy level

NOMENCLATURES

1. Acronyms

MER	Macroscopic Energy Representation
HESS	Hybrid Energy Storage System
FC	Fuel Cell
SC	Supercapacitors
EV	Electric Vehicle
HIL	Hardware-In-the-Loop
SIL	Hardware-In-the-Loop

2. Symbols / Parameters

$U_{dc}$	: Voltage supply
$I_{ch}$	: Load current
$U_{mot/gen}$	: Motor/generator voltage
$I_{mot/gen}$	: Motor/generator current
$T_{mot/gen}$	: Motor/generator torque
$V_{mot/gen}$	: Motor/generator speed
$E_{mot/gen}$	: Electromotive force motor/generator
$V_{ref}$	: Reference speed
$V_{veh}$	: Vehicle speed
$T_{res}$	: Resistant torque
$F_{res}$	: Force resistance
$F_{wheel}$	: Wheel force

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### BIOGRAPHIES



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