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Simcenter Amesim virtual validation of a BEV using EMR methodology

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Abstract— As stricter regulations on air quality are imposed on automotive manufacturers, simulation is playing a more important role in the electric vehicles design and production. Virtual testing helps reduce the costs of assessing vehicle performances and flaws which can be corrected early on, before the real testing is begun. This paper presents the validation, using Simcenter Amesim, of a virtual battery electric vehicle model with real measured data from the real Renault Zoe vehicle on track. The validated models give confidence in future reuse for other virtual testing scenarios, allowing to perform the tests in the digital domain, early in the development cycle, without the need of expensive and time-consuming real testing platforms.

Keywords— *electric vehicles, Energetic Macroscopic Representation, Renault Zoe, 1D simulation, validation, Simcenter Amesim*

I. INTRODUCTION

Battery Electric Vehicles (BEVs) are one of the solutions to improve air quality in populated areas [1]-[3]. To facilitate the transition from fossil fuel engines to electric motors in vehicles, simulations done in the digital domain are developed [4]-[7]. They use models, which are either physics driven or data driven, to capture the vehicle properties of interest for considered testing scenarios. These models have to be calibrated to the specifications of the vehicle in study and have to be validated by testing their predictive capabilities against the real vehicle measurements. Validation assesses the quality of predictions a model can make and as such it is an important factor in virtual simulation development that needs to be addressed. In a previous work, the authors have realized a first basic model of an electric vehicle under Simcenter Amesim [7]. This model used a permanent magnet synchronous machine and a simple electric model of the battery. In this work, the model of the vehicle is more developed. In fact, the battery model is an electro-thermal model developed in [8]. Furthermore, the real electric machine of the vehicle, a wound rotor synchronous machine is modeled.

The European H2020 project PANDA aims to speed up the vehicle development of the new vehicle architecture,

hybrids, fuel-cell and electric vehicles. In that aims, the PANDA project proposes to standardize the model or simulations realized in the different development tasks. The objective of this article is to present the validation of an electric vehicle model using the Energetic Macroscopic Representation (EMR), a flexible tool of organizing models in Simcenter Amesim. This paper presents the validation of a BEV model developed within the framework of the PANDA H2020 project. The complete vehicle model is organized using the Energetic Macroscopic Representation (EMR), which allows the clear delimitation of the subsystems and emphasizes power transfers between elements through power variables. In this way, the validation of the complete model is facilitated by first validating the components and then validating the entire vehicle model. The BEV model is validated by comparing simulation variables, calculated in Simcenter Amesim, with measured data from the real system. Real testing scenarios were defined in terms of specifications and carried out on tracks with a Renault Zoe vehicle by Renault Technologie Roumanie. Key vehicle variables have been measured to be used for validation.

Section 2 presents the graphical formalism and software used in the article. Then, the vehicle model is described in section 3. The scenario used for validation is presented in Section 4. Finally, the validation of the complete model is realized in section 5.

II. GRAPHICAL FORMALISM AND SOFTWARE

A. Energetic Macroscopic Representation

EMR is a graphical representation of the mathematical model of a dynamic system that highlights its energetic properties [9]. It organizes the model into a network of interconnected basic elements which perform basic energetic functions (Fig.1). The interconnection of elements is done through the interaction principle meaning that interacting variables are defined as action and reaction pairs which define power exchange. In addition, all the elements are described using physical integral causality meaning that the output is an integral function of the inputs.

The EMR is a functional description because it is describing subsystems using basic energetic functions as opposed to structural representations which describe the system based on the components structure. This aspect makes EMR fit for development of Energy Management Systems and Control Systems. In EMR, the physical system is made distinguishable to the control system through the color of the pictograms: yellow and green for the physical elements and blue for the control elements.

The EMR library in Simcenter Amesim [10] developed in the PANDA H2020 project is used to create the EMR simulation of the BEV in this paper. The EMR elements are made readily available, so the EMR structure of the system can be defined in Simcenter Amesim. Then, the EMR elements are populated using block-diagram elements from the Signal and Control library to implement the model equations.

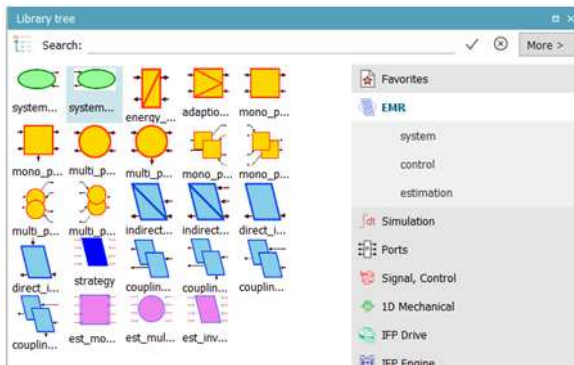


Fig. 1. The new EMR library developed in Simcenter Amesim

B. Simcenter Amesim

To face growing competitive pressures of the development of electric vehicles, dedicated software as Simcenter Amesim are used [7][10]. The current study is performed by using the modeling and simulation capabilities of Simcenter Amesim software, as an integrated, scalable system simulation platform.

III. VEHICLE MODEL

The BEV studied in this paper is the Renault Zoe Q90 that was used as a reference for BEVs in the PANDA project. The Renault Zoe is a small passenger electric car produced by the French manufacturer Renault. It was one of the most sold electric cars in Europe.

The structure of the BEV under study is a typical structure of a BEV presented in [3], where the vehicle specifications for the Renault Zoe version Q90 are given in Table 1.

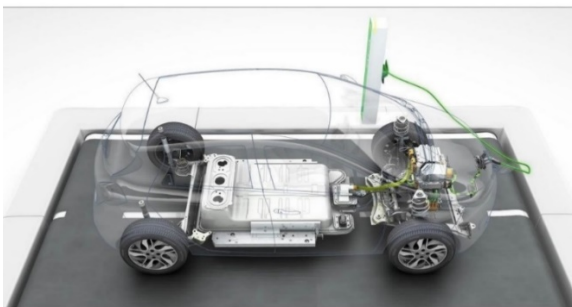


Fig. 2: Powertrain structure of Renault Zoe

First, the vehicle component models of the BEV are presented and then the complete vehicle model of the Renault Zoe, by integrating the components into the vehicle configuration. The vehicle model is composed of the battery, the e-drive and its control, the vehicle dynamics, and the auxiliary consumers.

Table 1: Renault Zoe Q90 specifications.

Parameters	Values	Parameters	Values
Body style	Hatchback	Electrical machine	Synchronous with rotor coil
Dimensions LxWxH (mm)	4084x1730x1562	e-machine max power (kW/hp) at max rpm	65/88 at 3000-11300
Weight (kg)	1480	e-machine peak torque (Nm) at max rpm	220 at 250-2500
Top speed (km/h)	135	On board energy (kWh)	41
Acceleration 0-100 km/h (s)	13.2	Autonomy NEDC (km)	370

A. Battery models

The battery model is an advanced equivalent circuit model (Fig. 3) with thermal modeling where the aim of the model is to reproduce the cell's electrical and thermal performances. Also, a dynamic behavior is included due to convection and diffusion phenomena through the RC network in the equivalent circuit model [8] [14-17].

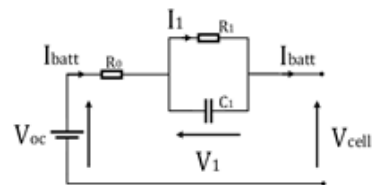


Fig. 3: Representation of the 1st-order Thevenin model

The thermal model considers the battery pack as a single thermal component with a single temperature point. The EMR of the battery model (Fig.4) implemented in Simcenter Amesim is shown in Fig.5.

The battery output voltage of the cell is calculated with the formula (1):

$$u_{cell} = OCV - R_1 I_{R1} - R_0 I_{batt} \quad (1)$$

where I_{batt} is the flowing current in the battery (A), and I_1 is the current passing in the polarization resistance (A)

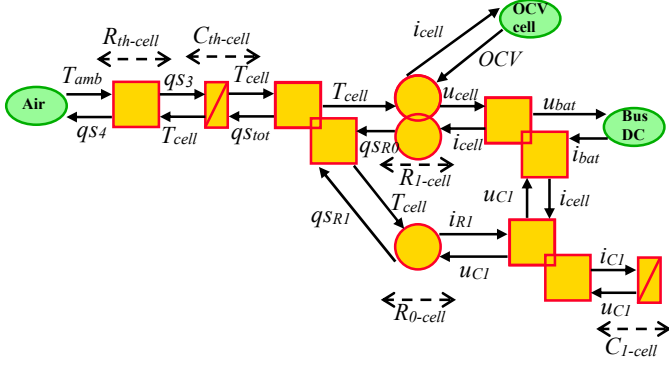


Fig.4: EMR of the battery model

The state of charge (SOC) is determined by the coulomb-counting method:

$$SOC = SOC_0 - \frac{1}{C_{init}} \int I_{batt} dt \quad (2)$$

with SOC_0 the initial state-of-charge of the cell. C_{init} is defined as the initial capacity (Ah) and it is assumed to depend on temperature and current:

$$C_{init} = f(T, I) \quad (3)$$

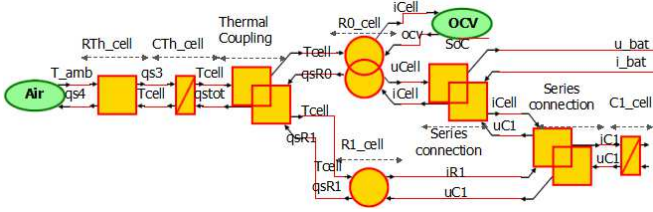


Fig.5: EMR of the battery model implemented in Simcenter Amesim

B. E-drive model

The e-drive contains the Wound Rotor Synchronous Machine (WRSM), the power electronics and the machine controllers [14]. The current at the input of the e-drive i_{ed} is the sum of the stator inverter current i_{inv} and the rotor chopper i_{ch} .

$$i_{inv} = i_{inv} + i_{ch} \quad (4)$$

The inverter is modeled as an average model inverter. The currents i_{inv} , $\underline{i}_{abc} = [i_a, i_b, i_c]^t$ and voltages u_{inv} , $\underline{v}_{abc} = [v_a, v_b, v_c]^t$ are linked by a modulation vector $\underline{m} = [m_a, m_b, m_c]^t$

$$\begin{cases} \underline{v}_{abc} = \underline{m} u_{inv} \\ \underline{i}_{inv} = \underline{m}^t \underline{i}_{abc} \end{cases} \quad (5)$$

Then a Park transformation is realized to express the stator variables in the dq reference frame.

$$\begin{cases} \underline{v}_{dq} = -[T(\theta_{d/s})] \underline{v}_{abc} \\ \underline{i}_{abc} = [T(\theta_{d/s})]^{-1} \underline{i}_{dq} \end{cases} \quad (6)$$

The chopper for the rotor is also modeled as an average model:

$$\begin{cases} v_f = f u_{inv} \\ i_i = f i_f \end{cases} \quad (7)$$

The WRSM is modeled as a lumped parameter model with constant parameters.

$$\begin{cases} v_d = R_s i_d + \frac{d\psi_d}{dt} - e_d \\ v_q = R_s i_q + \frac{d\psi_q}{dt} - e_q \\ v_f = R_f i_f + \frac{d\psi_f}{dt} - e_f \end{cases} \quad (8)$$

The electro-mechanic conversion is expressed as follows:

$$\begin{cases} T_{em} = p(\psi_d i_q - \psi_q i_d) \\ e_d = p \Omega_{em} \psi_q \\ e_q = p \Omega_{em} \psi_d \\ e_f = 0 \end{cases} \quad (9)$$

The controller used is an indirect field-orientated controller. The EMR of the e-drive model is shown in Fig.6 and its implementation in Simcenter Amesim in Fig. 7.

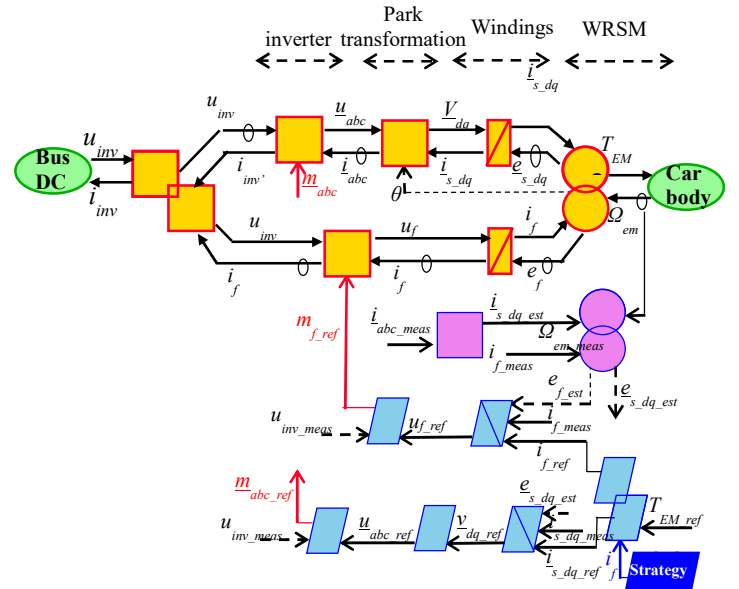


Fig. 6 EMR of the Wound Rotor Synchronous Machine

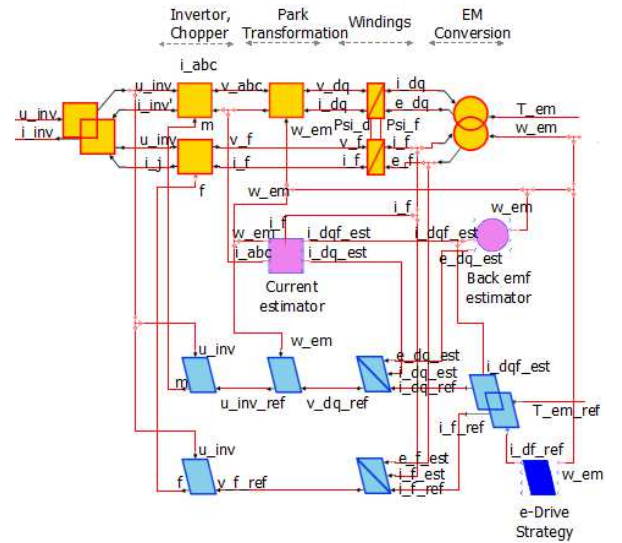


Fig. 7: EMR of the e-drive model and control implemented in Simcenter Amesim

C. Body model and auxiliary consumers

The body model consists in simple longitudinal vehicle dynamics with resistive forces (aerodynamic, road friction, road gradient) and the vehicle mechanical transmission (Fig. 8). The auxiliary consumers are modeled as a single ideal current load. The equations of this part are given in [15].

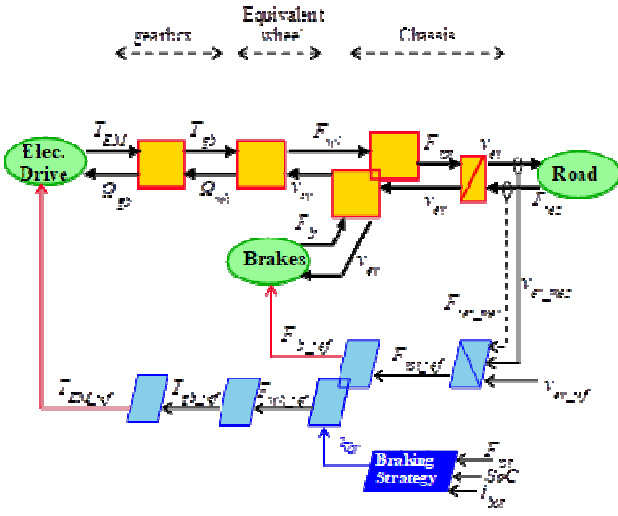


Fig. 8 EMR of the body car

D. Vehicle model

The vehicle components are easily integrated in a vehicle model thanks to the EMR organization, by interconnecting the corresponding EMRs of the components. The EMR of the vehicle model implemented in Amesim is shown in Fig.9.

IV. TESTING SCENARIOS

The validation of a virtual vehicle [15] involves the comparison of the results obtained from simulations with real data. All the vehicle component models should be able to be tested through simulation individually for their own performances and should be able to be used for simulations

of the vehicle performances. For this reason, validation data was measured from the real vehicle in specified scenarios made specifically to respect these requirements.

Various validation goals adapted for a BEV were defined in the PANDA project. The present paper presents the scenario where the defined Renault Zoe vehicle ran on an urban cycle road.

The urban cycle on which data were measured was done in Bucharest, Romania in heavy traffic conditions and on a warm summer day (Fig. 10). This test is representative of the usual driver's use which is in traffic in urban areas for daily activities. The measured urban cycle presented in Fig.8 shows a large variation of speeds with some stop times and some periods of speeds above 100 km/h. The duration of the trip is 2h26 min (8760s).

The measured distance was long enough to compare and evaluate the total energy consumption of the car which is one of the key parameters to evaluate the autonomy of the car.

The data was collected from ECU measurements. The Battery Management System was used to measure battery related variables, the Power Electronics Block control unit was used to measure inverter variables, and the Electric Vehicle Computer was used to measure variables related to global coordination of the electric powertrain.

An optimized sampling time for the measurements was determined to be at 1 Hz, considering factors such as internal transmission speed, computing speed and output transmission speed.

This cycle has many accelerations and braking stages which highlight the capability of the vehicle in recovering energy from braking. There are also constant speed regions appropriate for evaluating the steady-state behavior of the model. High-speed regions are also present when the vehicle is driven on express roads in Bucharest. Such a cycle is relevant for the use of the average European driver.

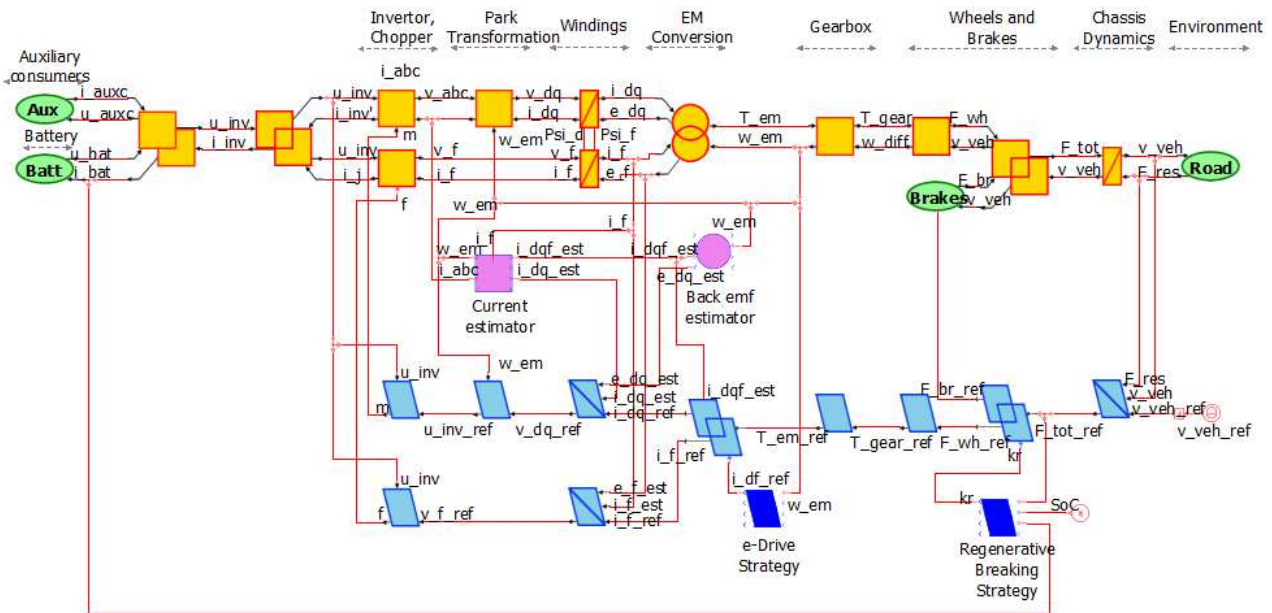


Fig. 9: Complete BEV EMR model

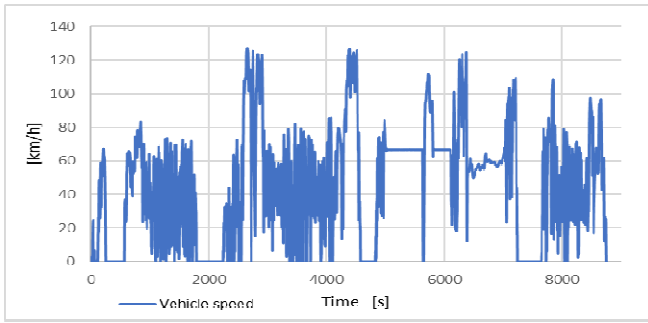


Fig. 10: Urban cycle

V. SIMULATION RESULTS

The simulation results are compared to measurements for the Urban cycle presented in Fig. 10.

Results from the simulation compared with corresponding measured parameters are presented. The virtual model is validated by doing an energy evaluation of the vehicle. Also the consumption of the car and how energy is transferred between components is analyzed. This will validate that the model is capturing physical interactions between components and that it is able to correctly evaluate battery consumption. The thermal model of the battery is validated to ensure that it is capable of providing precise battery temperature.

The power of the electric motor is shown in Fig. 11, while the voltage is given in Fig. 12. The energy consumed is in Fig. 13, SOC (state of charge) in Fig. 14, while the battery temperature is presented in Fig. 15 for both real (in red) and virtual (in blue with a dashed line) vehicles.

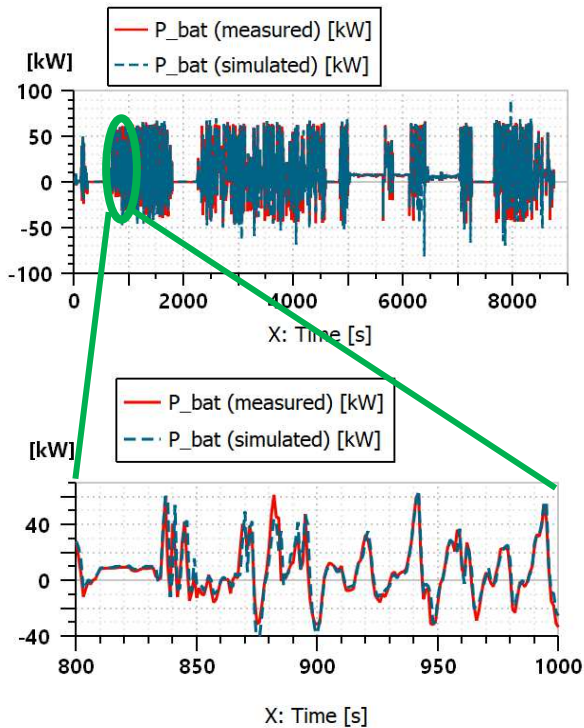


Fig. 11: Urban cycle: Battery power

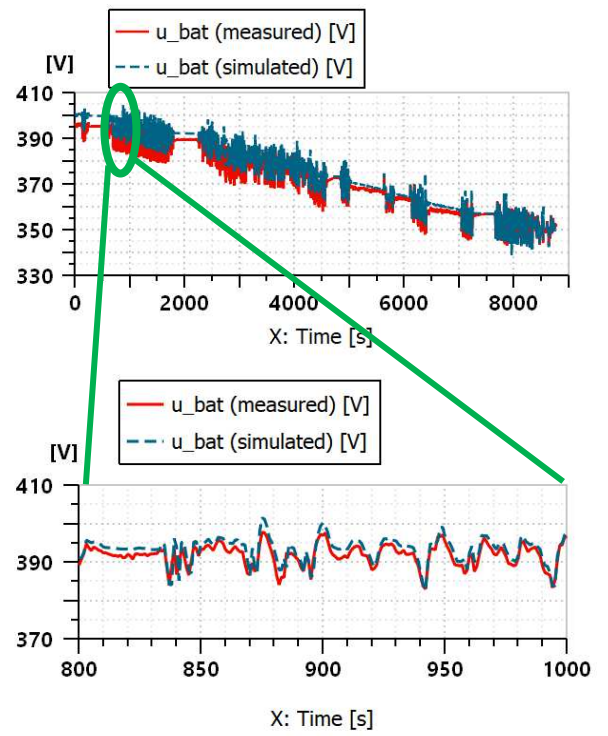


Fig. 12: Urban cycle: Battery voltage

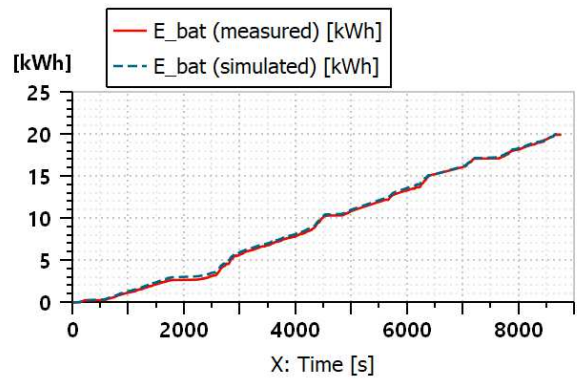


Fig. 13: Urban cycle: Energy consumed

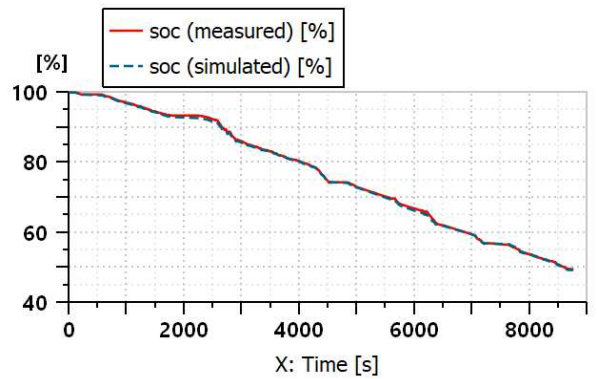


Fig. 14: Urban cycle: Battery state-of-charge

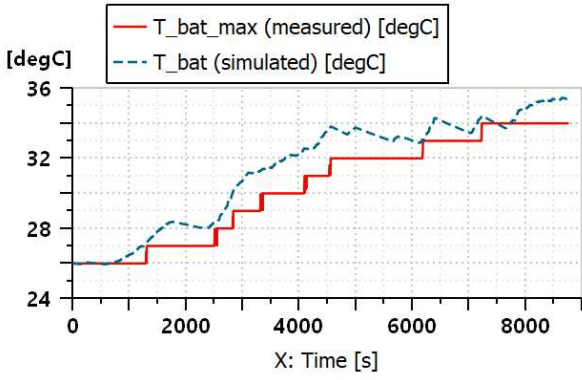


Fig. 15: Urban cycle: Battery temperature

The errors for energy consumption and the SOC are quite low within the 2% limit as they are calculated from equations (2). It is reminded that any variation within the 2% error range has no real significance due to the measurement accuracy.

$$\begin{aligned} \text{err}(E_{bat}) &= \left| \frac{E_{bat,meas} - E_{bat,sim}}{E_{bat,meas}} \right| \cdot 100\% = 0.51\% \\ \text{err}(SOC) &= |SOC_{meas} - SOC_{sim}| = 0.30\% \end{aligned} \quad (10)$$

The average error in temperature prediction, on the whole 8763 s cycle, is

$$\text{err}(T_{bat}) = \left| \frac{T_{bat,meas} - T_{bat,sim}}{T_{bat,meas}} \right| \cdot 100\% = 3.43\% \quad (11)$$

Even though the temperature is not measured accurately, the prediction error validates the thermal model of the battery as the error is under 5% and gives confidence in future temperature predictions.

VI. CONCLUSION

Virtual testing helps to reduce the time and cost of evaluating vehicle performances and tends to decrease the actual testing and the number of prototypes developed.

An urban driving scenario was defined to be representative of the real scenarios that a driver of a car may be part of. The validation data collected from such experiments tested the virtual model in the usual conditions in which a vehicle is used in real life.

This paper presents the physical results of the tests on the vehicle compared with simulation results. The results obtained show the capability of Simcenter Amesim to realize precise simulations by using the EMR methodology.

As a result, the validated model offers great confidence in predicting vehicle behavior in real life conditions with an accuracy higher than 98 % in energy consumption.

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