EMR Modeling of Mobypost

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Abstract— The development of high-confidence, real-time capable simulation models for virtual and hardware-in-the-loop testing offers new opportunities for the automotive industry in terms of virtual product development and production to reduce the time-to-market of the fuel cell electric vehicles (FCEVs) at lower costs. However, the challenge is the combination of the hybridization and electrifications in the FCEVs leading to significantly increased vehicle variants and increased system complexity. In this paper, a unified organization of digital models is applied with the objective to seamlessly integrate virtual and real testing as proposed in the PANDA project is presented. This tool is than applied to the postal delivery FCEV developed during the Mobypost project and its components at the vehicle level. The model can reflect that the method developed during the PANDA project is capable to describe the Mobypost vehicle with its multi-domains, including electric, magnetic, mechanical and chemical. Besides, by simulating a complex road environment, the proportion of power and energy between battery and fuel cell can also be provided for the optimization of the FCEVs parameters.

Keywords—Energetic Macroscopic Representation, Fuel Cell Electric Vehicle, Postal delivery vehicle

I. INTRODUCTION

Mobypost is a type of fuel cell electric vehicle (FCEV) for postal delivery aiming at developing a novel sustainable mobility concept that can meet the challenge of combining a carbon-neutral vehicle with a hydrogen fuel cell, for which the hydrogen is produced on spot from renewable sources. The Mobypost vehicle has a strategic role in the hydrogen-driven vehicle because of its innovative way to generate and manage the power on-board [1][2]. As shown in Fig 1, in order to design the vehicle using virtual test, the real driving cycles were studied in depth and used as the input of the simulation. The driving cycle was thus based on the statistical data extracted from experimental test obtained from the real vehicle. After the calculation, the mean power, the battery capacity and the hydrogen mass during the driving cycle were obtained, implemented and tested [3][4].
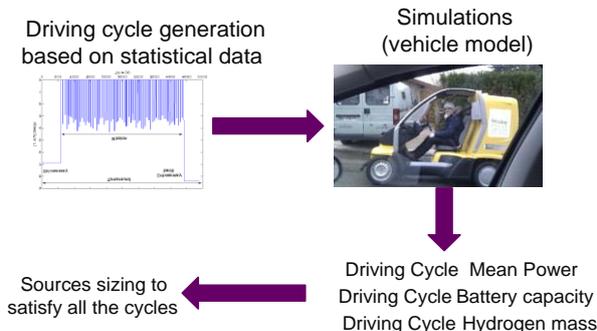
Figure 1: Virtual testing cycle

It can be seen, that compared with the traditional carbon vehicle or electric vehicle, the combination of the hybridization and electrifications in the Mobypost features more vehicle variants and increases system complexity [5][6]. Inside the Mobypost, electric energy storage systems (ESSs), electric machines, and power electronic converter are three basic components. ESSs use battery cell and Proton-exchange membrane fuel cells (PEMFC) providing the power for the FCEVs. Regarding the electric machine, interior permanent magnet synchronous machine (PMSM), are commonly used.

Even though the Mobypost vehicle was developed and tested in a former research project, it is an interesting platform in the scope of the PANDA project. The objective of the Horizon 2020 project PANDA is to provide a disruptive and open access model organization for an easy interconnection and change of models in the development process of EVs, with the goal to obtain a simple interoperability between software testing and Hardware in the Loop (HiL) testing. In this context, a precise definition of the modelling approach is essential. The energetic macroscopic representation (EMR) formalism is a solution [3]. The widely used classical structural approach, consists of associations of physical components in order to focus on the system structure/organization/topology. EMR, on the other hand, is a causal cognitive functional approach, which can be used for the analysis and construction of FCEVs models applicable and the power flow [3,4]. By refining the predefined class of problems, the accuracy of the model can be improved [5].

II. PANDA BASED EMR REPRESENTATION OF MOBYPOST

As shown in Figure 2, ESSs, electric machines, and power electronic converter are three main functional blocks in electrified transportation. In this part, we focus on modeling of the ESSs, power converter, electrical machine and the mechanical loss in the road condition. The presented results are based on former works that were not based on EMR [6]. It should be highlighted that EMR is a representation tool, it imposes the model structure as well as inputs and output parameters. However, it does not specify the type of model used. In the following, the used models are introduced. However, they can be updated later.

A. Mobypost EMR Structure

Equivalent circuit models (ECM) are used to build the model of the PEMFC, Figure 3. Usually, ECM represents a particular fuel cell stack operating at nominal conditions of temperature and pressure. And a diode model is used to prevent the flow of negative current into the stack. Based on the polarization curve obtained from the datasheet, the parameters of the ECM can be obtained [6,7,10].

For a Battery Cell, the input variables are the load current and internal core temperature. The ECM model calculates the combined voltage of the network battery in function of state-of-charge (SOC) and battery temperature. The output variables are the SOC and terminal voltage, Figure 4, [6,8].
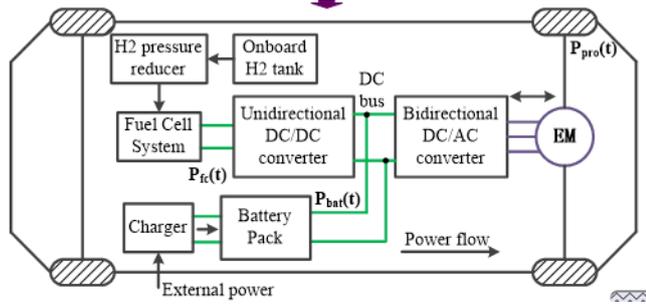
Figure 2: EMR Mobypost
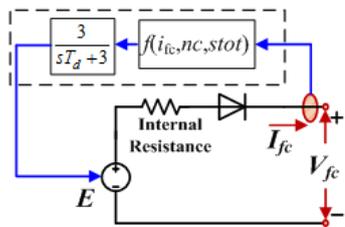
Figure 3: EMC of fuel cell stack [9]
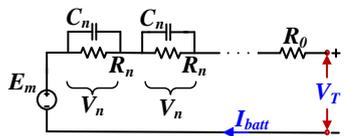
Figure 4: EMC of Lithium Battery Cell

Since the study focuses on the power flow of the FCEVs, the simplified average model is used. The input voltage/current is proportional to the output voltage/current with the ration of the modulation indexes m_r from the converter control [9,10], Figure 5.
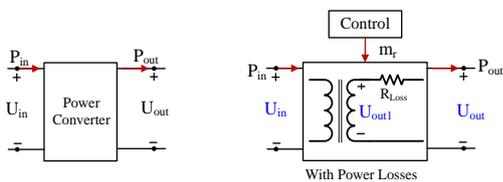
Figure 5: EMC of power electronic converter

In electrified powertrains, the efficiency and performance of the electric machines have a significant impact on fuel consumption, acceleration, high-speed performance, and driving comfort. In the dq frame, the input three phase's voltages are calculated to v_sd and v_sq after Clark conversion [11], Figure 6.
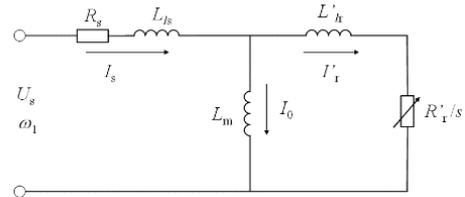
Figure 6: EMC of Electric Machine

The propulsion system produces mechanical energy that is assumed to be momentarily stored in the vehicle. As shown in Figure 7, the amount of mechanical energy consumed by the following three effects:

• The aerodynamic friction losses;
• The rolling friction losses;
• The energy dissipated in the brakes [6].
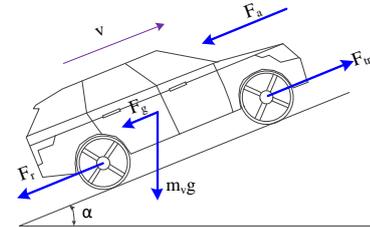
Figure 7: Vehicle Dynamics

Even though the Mobypost vehicle was developed and tested in a former research project [6,7,8], it is an interesting platform in the scope of the PANDA project. The objective of the project PANDA is to provide a disruptive and open access model organization for an easy interconnection and change of models in the development process of EVs. In this context, a precise definition of the modelling approach is essential. The energetic macroscopic representation (EMR) formalism is a solution [3]. The widely used classical structural approach, consists of associations of physical components in order to focus on the system structure/organization/topology. EMR, on the other hand, is a causal cognitive functional approach, which can be used for the analysis and construction of FCEVs models applicable and the power flow [4]. By refining the predefined class of problems, the accuracy of the model can be improved [5]. The main objective of the PANDA project, due to the use of a unified approach, is to obtain a seamless transition from modelling to hardware testing via HiL.

B. The EMR modeling of the Inversion Control

In order to organise the model of an energy conversion system, only 4 energetic functions are sufficient. EMR is thus based on 4 basic pictorams. An inversion-based control (IBC) can be systematically deduced from EMR using specific inversion rules [3,11].

Each EMR element of the tuning chain is inversed to deduce the control chain, where all these paths connect the different vectors using signal arrows. The control structure is developed by a block-wise inversion of the system model, which is represented by parallelograms with an oblique bar [3,11,12]. The IBC and the EMR model of FCEVs are shown in Figure 8.
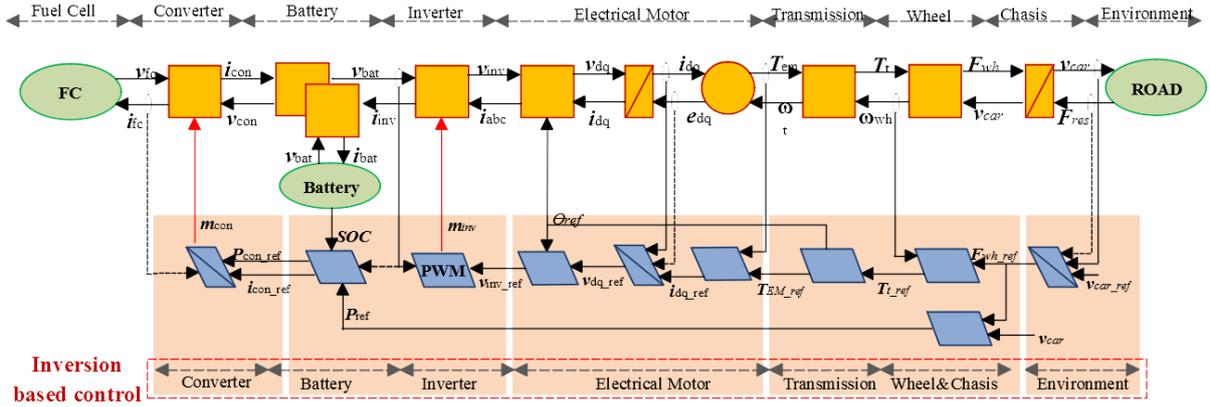
Figure 8: EMR and IBC of Mobypost

III. SIMULATION RESULTS

Based on the EMR model in Figure 8, the simulation results are shown in the following. Figure 9, shows the driving cycle. As expected for a postal delivery vehicle, this driving cycle shows a relative low mean velocity of around 30 km/h and multiple stops, with associated multiple accelerations and decelerations. This translates in peaks of force both in positive direction (acceleration) as in negative direction (deceleration). It is obvious that for such a use energy buffers are required that are able to store energy while braking and provide energy while accelerating. This task is covered by the batteries in this case whereas base load is covered by the fuel cell system. It can be seen, that he demanded driving cycle can be satisfied by the system.
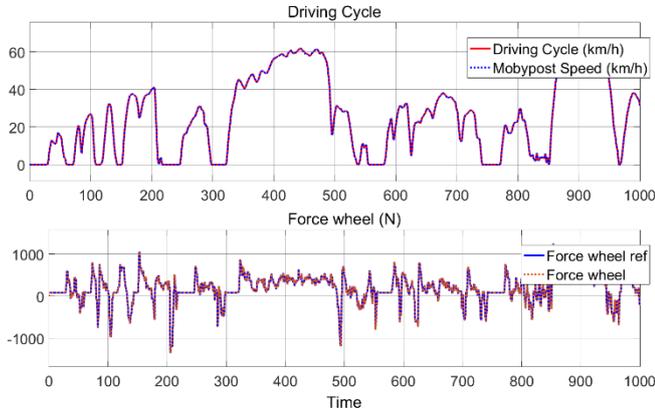
Figure 9: Vehicle dynamics containing driving cycle and wheel forces
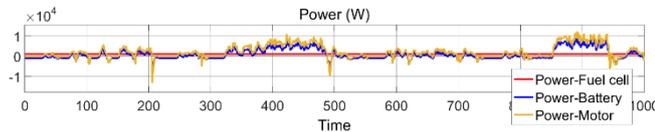
Figure 10: Power Analysis

Figure 10 provides the power analysis of the given driving cycle. It can be seen that the power provided by the fuel cell is constant and rather low at around 1kW. However, if the calculation over the working day is done, it can be seen that the fuel cell provides the mean power demand of the vehicle. This rather simple energy management approach is the result of an initial study [6]. As described above, the battery acts as buffer and can provide power peaks of 7.5kW positive and 5kW negative power. Moreover, the net SOC is decreasing from 0.71 to 0.65 during the studied driving cycle.

A closer look on the battery use as provided in Figure 11 shows the battery current, voltage and SOC evolution over the driving cycle. Current peaks from -100A to +150A can be observed, whereas the voltage only varies between 50V and 55V. At the same time the fuel cell is running on constant power, which explains a constant current of 39A and 26V voltage and the linearly increasing hydrogen consumption.
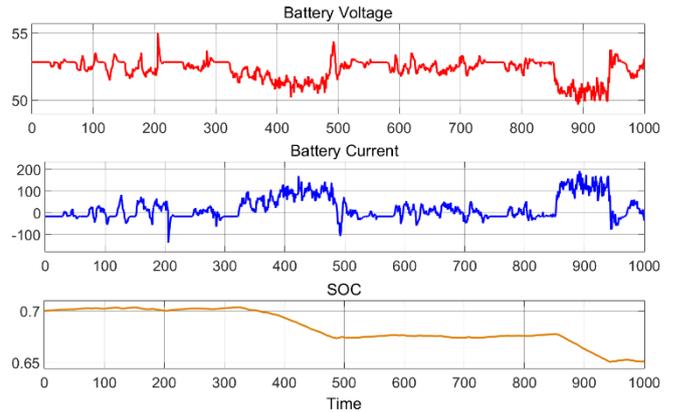
Figure 11: Battery use

Finally, the electric machine can be studied. Figure 12a) provides the electrical values. In this simple case the *Iq* current stays equal to zero. However, another part of the PANDA project covers the coherence between simple and more complicated electric machine working modes [13]. The *Id* and *Iq* currents are translated into *Ia, Ib* and *Ic* currents and the inverter DC side currents can also be seen and are in coherence with the battery and fuel cell currents provided in Figure 11. Figure 12b) shows the mechanic data of the electric machine including the motor speed, which is proportional to the vehicle speed presented in Figure 9. and the motor torque, both combining to the motor output current.

In conclusion it can be stated that compared with the reference (the input driving cycle), the simulation results have a high consistency with the velocity reference and the simulated power requirement agrees with the calculated power requirement.
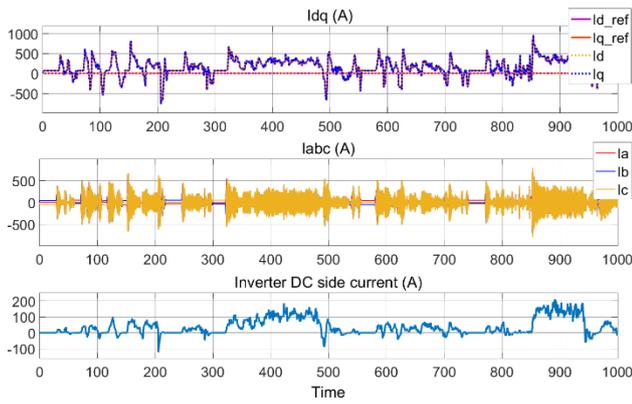
a) Electric
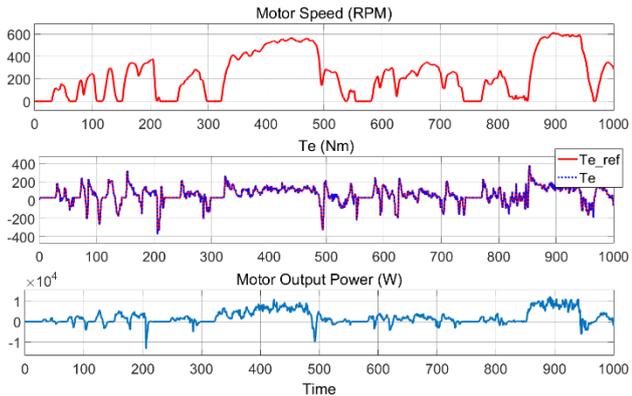
b) Mechanic

Figure 12: Electric Machine a) electric, b) mechanic

IV. CONCLUSIONS AND FUTURE WORK

This paper presents a general modeling method to implement the real-time model of FCEV using the EMR approach. The representation consists of two parts: the FCEV model and the inversion-based control. The EMR allows the seamless integration of different subsystems, including ESSs, power converter and the electrical machine; By defining the connection ports in each EMR block, the model is able to cover different physical variables, like electric, magnetic, power losses, mechanical and chemical. Based on the numerical calculation of each EMR block, the inversion-based control can also keep the same structure as the modeling part.

Future works include the use of the presented model in the context of the PANDA project with the goal to have a seemless integration of the model in HiL.

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