Brake Blending Strategy on Electric Vehicle

Co-simulation Between MATLAB Simulink® and Simcenter Amesim™

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***Abstract*—Application of regenerative braking on electric vehicles has to be carefully optimized in order to maximize the system efficiency, maintaining high performance and reliability levels that are required by the automotive sector. Considering complex interactions arising from the interaction of electric brake plant with vehicle dynamics and other on-board sub-systems, there is the necessity of modular scalable models able to merge multiple competences and different engineering tools, aimed at performing accurate simulation activities. In this work authors present some preliminary results concerning the implementation of a model in which the potentialities of co-simulation between different environment are exploited.**

Keywords—Electric Vehicle; Fiat 500e; Brake System; Brake Blending; Mechatronics;Electric Powertrain Optimizazion

I. INTRODUCTION

Recent growing of Electric Vehicle's (EV) technology offers the opportunity of new green sustainable transportation systems able to drastically improve energy efficiency [1].

The technological features of modern electric powertrains (e.g. faster bandwidth response, precise torque control, etc.), offers to designers a wide range of functionalities that are very innovative respect to performance constraints affecting conventional solutions, based on Internal Combustion Engine (ICE) [2]. Four-quadrant capabilities of modern electric drives employed in the automotive field [3],[4] allow regenerative braking, increasing autonomy and efficiency of the EVs [5]. Regenerative brake can provide a reduction of 15-20% of the overall consumed energy, as demonstrated in literature [6],[7], on the basis of real-world driving cycles simulation [8] and road testing [9]. Also, an extended application of regenerative braking system involves a drastic reduction in the wear of the brake friction components [10]. This is a very interesting feature, not only in term of maintenance costs: debris produced by worn brakes are one of the most important sources of pollution [11]. Conventional friction brakes cannot be removed in a short-term scenario, since their performances are quite fundamental to assure a safe back-up in case of unavailability of the electric regenerative braking [12]. Finally, it should be considered that for many fundamental functionalities, such as stationary parking brake, the adoption of a friction brake still represents a simple and feasible solution.

In this work, financed by the European project OBELICS [13] *(Optimization of scalaBle rEaltime modeLs and functIonal testing for e-drive ConceptS),* authors have investigated the opportunities offered by the co-simulation between different tools: *MATLAB Simulink*® and *Siemens Simcenter Amesim*™.

Regenerative braking and brake blending are common topics in railway engineering where authors have gathered few previous research experiences [14]. This previous know-how has been exploited and merged with more recent experiences focused on automotive applications [15]–[18].

More generally all these references confirm the importance of a strong synergy in the design of both electric powertrain and conventional brake plant.

Also, fundamental on-board sub-systems devoted to vehicle safety and stability (i.e. ABS or ESP) are commonly interfaced with brake plant. In previous works [18],[19] authors have started to investigate this complex interaction on a simplified vehicle model with 3 Degree Of Freedom (DOF).

In this work, the attention is more focused on the simulation of regenerative braking and on the benefits arising from the possibility of exploiting co-simulation features between different simulation tools. In particular, it's proposed a simplified co-simulation layout between a model of the brake plant and a corresponding simplified vehicle model.

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Data concerning the proposed benchmark vehicle are made available from CRF (Fiat Research Center).

The models have been designed in order to allow, in a short-term scenario, the adoption of general purpose interfaces, such as FMI (Functional Mock-up Interface) [21], in order to demonstrate the possibility of a full interoperability between different simulation environments. Considering multiple possible application of the proposed tools, ranging from preliminary design to Hardware in the Loop (HiL) testing, authors also optimize model implementation for a possible Real Time (RT) execution, even on distributed networks. In this latter case, to compensate reduced communication bandwidth between distributed computational resources and to allow a more efficient simulation of weakly coupled system, authors have suggested the application of numerical methods that have been successfully established in previous research activities [22].

II. AIM OF THE PROPOSED WORK

In the context of the OBELICS project, the proposed models are developed in the perspective of preserving the scalability, modularity, flexibility, abstraction and RT capability.

These mentioned features are necessary for achieving the main aims of this work: verify the interoperability between the *UniFi Brake Model (UBM*), and the so-called *Vehicle Model (VM)*, while ensuring the standardization and the applicability of the models respect to numerous different EVs Use Cases (UCs), proposed by the project's partners. Also, the potentiality of a co-simulation approach is exposed.

III. MODELLING APPROACH

Setting up of the simulation environment requires the modelling of many subsystems, dedicated to reproducing the behaviour of a wide range of different phenomena occurring during realistic operational scenarios.

In Fig. 1 is reported a representation of the simulation layout. As previously mentioned, the followed approach involves the use of two different simulation software: MATLAB Simulink$^{®}$ (developed by MathWorks$^{®}$) and Simcenter Amesim™ (by Siemens), in which are respectively implemented the UBM and the VM.

A. Unifi Brake Model

The UBM (Fig. 2) consists of two different subsystems:

- Br*ake Blending Controller*: a vehicle control unit which applies the corresponding blending strategy that optimizes and regulates the way in which regenerative and conventional braking efforts are applied together.
- *Hydraulic Brake Plant*: a model able to reproduce the behaviour of a real brake system, that transforms the desired braking demand in the appropriate clamping force to the calliper which push the pads against the disc.

The Brake Blending Controller (BBC) should consider some limitations, relative to the actuation devices. The availability of several brake sources makes appear the vehicle an over-actuated system, whose effort must be constrained by some steady and variable physical limit conditions:

- **Electric Units**: a motor whose torques should be limited according to powertrain and battery status.
    - *Electric Motor:* It must be controlled in order to perform the ideal traction/braking characteristic, so in the iso-power section deliverable torque is reduced with the square of the speed [23].
    - *Battery:* to avoid over-charge and under-discharge situations, overheating or other undesired occurrences, electric traction power must be limited at low SOC values, while regenerative braking must be limited at high SOC values.
- **Friction Brake Units**: pads that are pushed against brake discs by callipers to dissipate the vehicle kinetic energy (under heat form) is constrained by maximum hydraulic deliverable braking torque.

Substantially, the BBC receives the traction and the braking command (dimensionless signal variable from 0 to 1, indicating the required longitudinal performance respect to its maximum and minimum admissible values) produced by the driver. Relying on this signal, the BBC decides how to split the requested brake demand between the hydraulic brake and the regenerative one, in the respect of the electric powertrain torque constraints (which must be protected in every operative scenario), while attempting to completely exploit the electric braking in the motorized wheels. Regenerative torque reference must be saturated to the maximum available value, reproducing the limitations of the simulated components (i.e. motor drive and Battery Management System BMS). In order to assure the safety and availability of the whole system, a conventional dissipative brake system is maintained. This element is fundamental in order to guarantee the minimum braking performance in every working condition.

Therefore, according to the aforementioned specifications, the action of the BBC should be able to compensate the unavailability of the actuation systems in several working situations, working adaptively, ensuring at the same time a certain minimum level of performance, able to guarantee a desired vehicle behaviour and safety level.

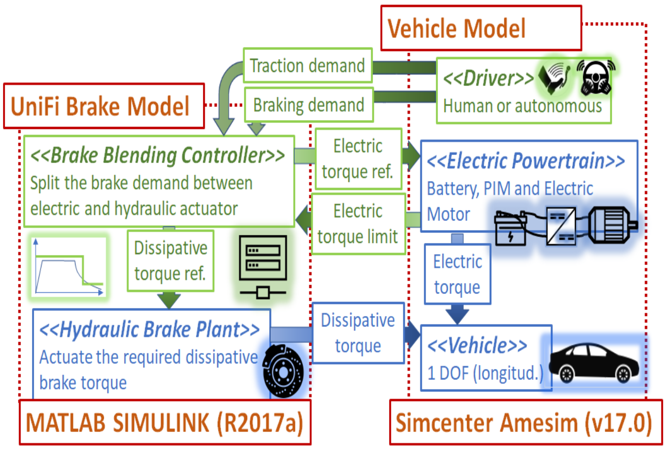

Fig. 1 Co-simulation environmental layout

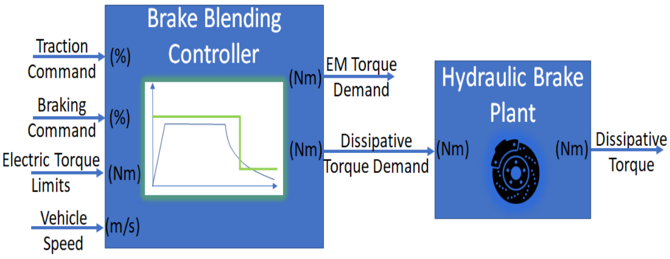

Fig. 2 Unifi Brake Model implemented in MATLAB Simulink®

The Brake Blending Controller is also capable to perform some specific functions, for which is necessary to estimate vehicle longitudinal speed. In particular, for the reference UC, it is advisable to disable the regenerative brake under a specific vehicle speed value, since the corresponding advantage in terms of recovered energy at very low speed is often negligible respect to additional complexity levels that are introduced in the system management. Finally, the control unit is designed to deliver a *"coasting braking torque"* (which value is fixed) when none of the accelerator and brake pedals are pressed. This functionality is implemented to reproduce the feeling of the engine brake effect on the pilot, similarly to what happens in conventional ICE vehicles. In this way controllability and drive comfort of the vehicle are highly improved [24]. This control unit is also able to manage even traction demand, generating the corresponding positive torque reference for the motor drive.

The *Hydraulic Brake Plant* is the model of the dissipative brake actuator which delivers the desired braking torques, reproducing the physical phenomena that occur in a real hydraulic braking system. This plant is supposed to be controlled in terms of desired torque performance: for this reason, it is equipped with a proper controller for the regulation.

The BBC strategies and the modelling of the brake plant have been widely described in previous publications [19],[20].

B. Vehicle Model

The modelled vehicle equipment consists of a series of different mechanical, electrical and electronic components, useful for the correct simulation of the vehicle behaviour (during traction and braking phase); i.e.:

- *Driver*: provides acceleration and braking commands based on the specified drive cycle, both variable from 0 to 1.
- *Vehicle Chassis*: for which is considered only 1 DOF in the longitudinal direction.
- *Electric Motor*: electrically connected to the high voltage battery and mechanically linked to the distributor shaft of the front axle differential. It is able to work on multiple quadrant (in this case the 1° and the 4°), reproducing the ideal traction/braking Torque vs Speed characteristic [23].
- *High Voltage (HV) Battery*: which deliver the traction power to the EM and receive the regenerated energy from the latter. It is equipped whit a BMS for the SOC estimation and its own torque limit calculations.
- *Power Integrated Module (PIM)*: DC/DC converter used to feed the auxiliary load (e.g. cooling/heating system, control unit, etc.) and a low voltage battery using the HV DC-bus.
- *Transmission*: simulates the presence of the reducer and the differential between the engine and front wheels.
- *Auxiliary Load and LV Battery*: components included for accurate calculation of the absorbed energy.

In Fig. 3 are displayed side and top schematic view of the vehicle, together with some of its main subsystems and dimensions, whose value are listed in TABLE I, freely available online.

C. Co-simulation Layout

There are two ways in which the co-simulation between the mentioned software can be performed.

The first one, used in this work, involves the use of a dedicated tools for the concurrent processing among the involved software. It enables a simple and fast data exchange, allowing the independent resolution of the corresponding model. Otherwise, the cooperative simulation could also be performed by exporting both model in the FMI standard (Functional Mock-up Interface) and solving them through a support interface software (MODELICA language). FMI represents an independent standard tool which supports data exchange between different simulation environments. By using a combination of xml-files and compiled C-code a *black-box*, exchange is possible without sharing knowledge of the system/model implementation. The black box itself is called Functional Mock-up Unit (FMU). However, one drawback of FMI standard is that the compiled C-code is platform depended. That means an FMU compiled for Windows cannot be used for another operating system e.g. Linux. Thus, it is important the model's contributors are able to compile C-code for various operating systems.

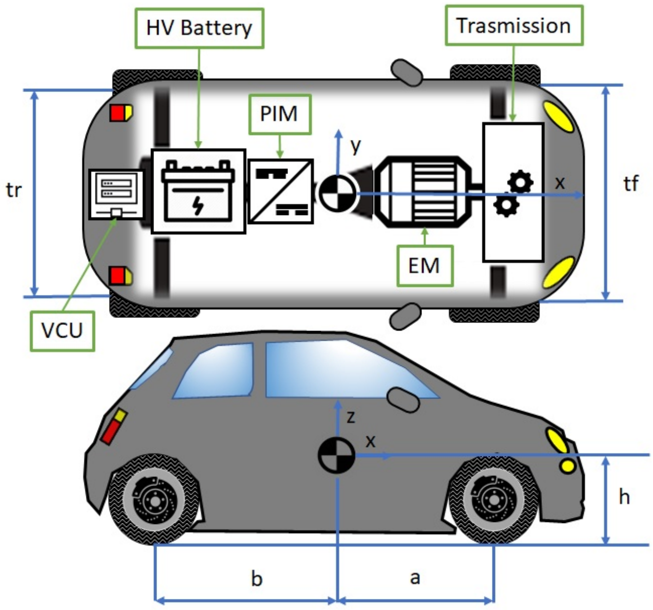

Fig. 3 Representation of the reference UC vehicle

TABLE I VEHICLE DIMENSIONS

CRF 500e Main Dimensions		
Variable	***Name***	***Value***
Mass	Mv	1320 [kg]
Front Track	tf	1407 [mm]
Rear Track	tr	1397 [mm]
Longitudinal Dist. Front Axle to CG*	a	989 [mm]
Longitudinal. Dist. Rear Axle to CG*	b	1311 [mm]
Vertical Dist. Ground to CG*	h	650 [mm]

*CG: center of Gravity

Fig. 4 shows the implemented configuration in Simcenter Amesim™ and integrates the *VCU (Vehicle Control Unit)*. Essentially, the VCU is an electronic device which comprises the BBC, that is the corresponding control algorithm implemented in MATLAB. The proposed model appears to be extremely simplified, for which is not considered, for example, the four-quadrant converter for the motor regulation. However, for the battery charging and discharging we impose directly on the BMS model the appropriate Voltage-Current profile[25]. This choice is made in the perspective of utilize the model not for an excellent validation of energy vehicle's energy performances, but to expose the co-simulations benefit and a rouge estimation of the regenerative braking advantages.

It is important to note that the system allows the possibility to adopt different sampling rate between models or sub-models, so the time step of the solvers included in the co-simulation environments may be different. Considering that occurring phenomena characterized by very different time-constants are often simulated together in mechatronics systems, this feature is highly desirable, since allows the use of an optimized resolution configuration according to the need of each subsystem, without compromising the data exchange between them. Therefore, each sub-model solver can be tuned independently, thus reducing the overall calculation effort without prejudice the accuracy.

IV. VEHICLE USE CASES DESCRIPTION

For this activity we decide to applicate the current study to a specific UC, which is an EV developed by one of the project partners: the *FIAT 500e*.

The reference UC vehicle (Fig. 3) is a purely electric front axle drive configuration EV. It is equipped with one EM and the generated torque is distributed among the frontal wheel through a differential mechanism.

The motor is able to deliver positive and negative torques to the distributor shaft, working respectively on the first and fourth quadrant, assuming for this work that the vehicle can move only in the positive longitudinal direction (cannot drive in backwards direction).

V. SIMULATION RESULTS

We can finally present some result arising from the performed simulations.

Firstly, we impose to the vehicle the execution of a certain reference manoeuvre, in order to determine the effectiveness of the blending algorithm. The manoeuvre consists of three different phases:

1. *Traction Phase*: from 0 speed to 144 km/h (40 m/s).
2. *Coasting Phase*: in which no pedals are pressed (both throttle or brake) and the EM provide a coasting braking torque on the driven wheels.
3. *Braking Phase*: where the vehicle slows down until is completely stopped (supposing a constant brake demand).

As visible in Fig. 5, the BBC correctly assign the effort applied by EM (traction and regenerative braking) and the disc brakes (mechanical braking) in order to maximize the recovered energy.

After this, we impose a well-known (in literature) speed profile to the vehicle, in order to evaluate its energy performances, shown in Fig. 6. As can be seen, the pilot model provides the correct pedal control so that the vehicle follows with high precision the desired speed profile: The *Worldwide harmonized Light vehicles Test Procedure (WLTC)*.

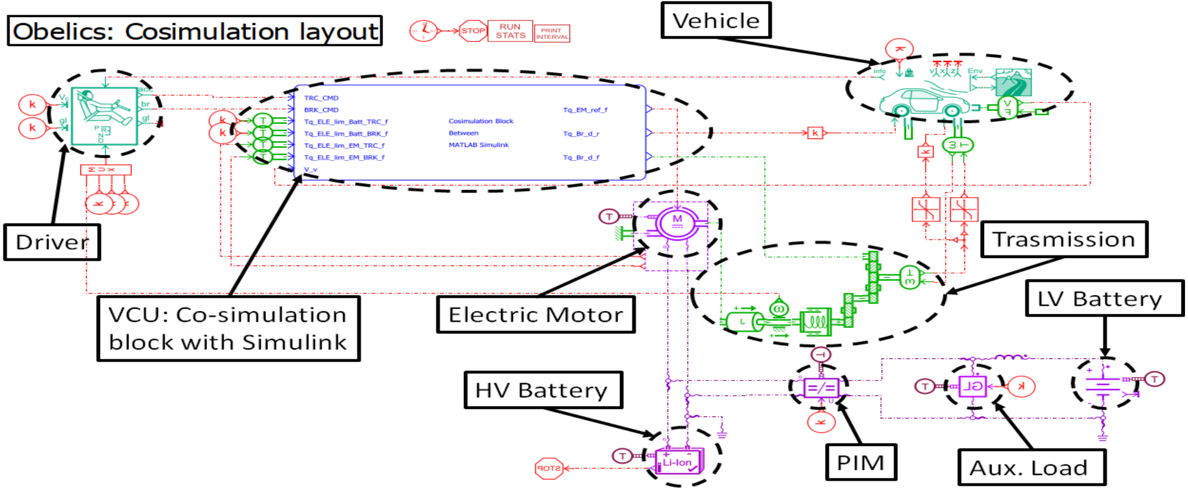

Fig. 4 Co-simulation layout implemented in the Simcenter Amesim™ v17.0 environmental for reference UC vehicle

For comparatively evaluate the results of this simulated scenario we consider multiple vehicle traction layout configuration: without regenerative braking, with regenerative braking on front axle and with regenerative braking in both front and rear axle. In Fig. 7 are expose the consumed and the regenerate energy profile during WLTP class 3 driving cycle for the previously mentioned powertrain configuration, while in Fig. 8 is visible the trend of the battery SOC, also in all mentioned cases. TABLE II, instead, show the overall consumed and regenerated energy, the final SOC_f of the battery (supposing an initial 60% of charge), along with the percent of the regenerated energy improvement obtained in the reference driving cycle.

VI. CONCLUSION AND FUTURE DEVELOPMENTS

The availability of the regenerative brake system consents to recovery part of the total consumed energy, about 15-18% as visible in TABLE II, depending of the adopted powertrain configuration, resulting in an increase of the overall efficiency and autonomy. This feature is highly desirable in the electric automotive field, where the presence of an electric powertrain make easy the integration of the regenerative system.

The Brake Blending strategy applied in this study appear to be extremely efficient and reliable, since address the maximum of the requested braking effort to the electric motor, in the respect of the corresponding constrains, leaving to the disc brake the burden to compensate a possible gap between the required torque and the one delivered by the EM.

For what concern the simulation potentiality, it seems that use a cooperative simulation environment can lead to the possibility to use different solvers and sample times for the integration of the implemented subsystem, while ensuring a fast data exchange between the used software.

The actual implementations allow the coupling between UBM and VM, whose integration is performed with the help of different solvers and sampling steps, reported in TABLE III.

The proposed co-simulation layout replicates the behaviour of a realistic EV well, both for what concern the brake system as its energy performance, automatically executing data extrapolation of the input signal, to ensuring the continuity of the exchanges data between the software. This feature is fundamental in order to compensate the delay effect arising by the use of different solver's sample time and communication interval.

TABLE II Vehicle Energy Performance During WLTP Class 3 Cycle

Vehicle Energy Performances				
Cases	***Consumed Energy [kJ]***	***Regenerated Energy [kJ]***	***Regenerated Energy [%]***	***SOC_f [%]***
No Regenerative Brake	1582.1 kJ	0 kJ	0 %	41,2 %
2x4 Regenerative Brake	1356.6 kJ	225.5 kJ	14.25 %	43,9 %
4x4 Regenerative Brake	1306.3 kJ	275.8 kJ	17.4 %	44,5 %

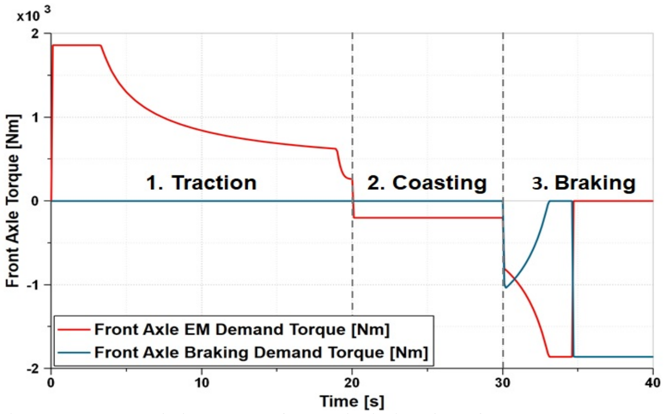

Fig. 5 Demanded torque on front axle during the reference manoeuvre

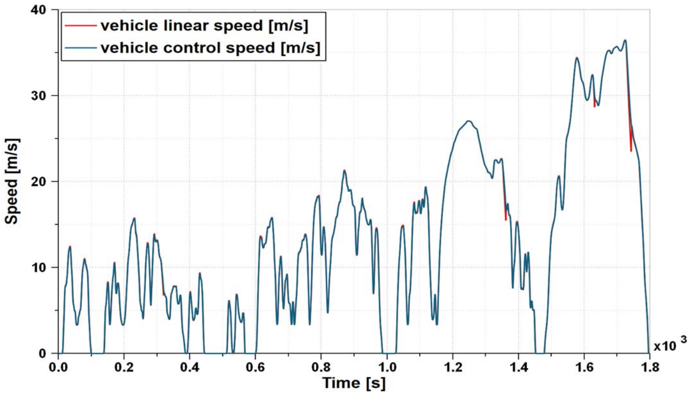

Fig. 6 Vehicle speed during a WLTC Class 3

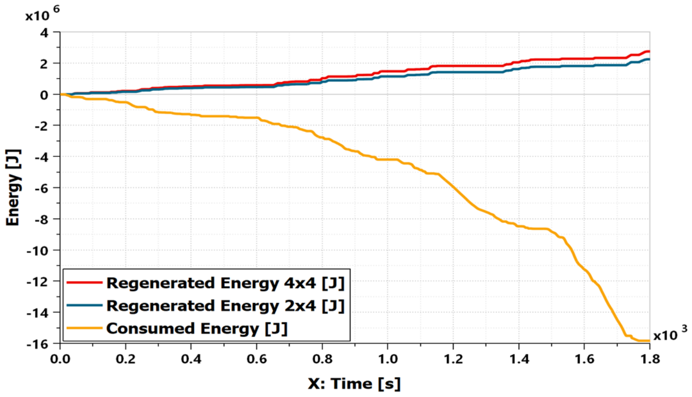

Fig. 7 Consumed and Regenerated Energy during a WLTC class 3

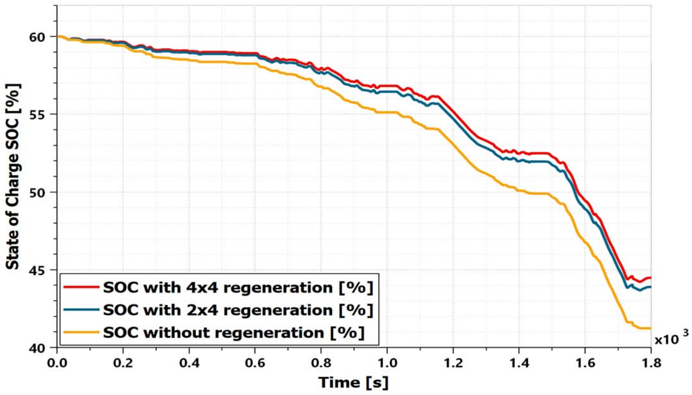

Fig. 8 Battery SOC trend during a WLTC class 3

This property occurs even in real application, when there is a communication between continuous and discrete system; so, the presence of this effect consent to further improve the consistency of the obtained results from the simulation environment. More generally, the developed model complies and fits with the required standardization specifications, allowing the extension of this work to further UCs.

Future developments concern the integration of the other's project partner subsystem, in order to refine the proposed model; as well as an FMI co-simulation implementation using MODELICA languages, with the intent to share IP (Intellectual property) protected models. The BBC will be slightly modified and used as VCU, in order to fit the particular EVs features specific for the investigated UC. To setup and execute the co-simulation we will uses a co-platform called AVL Model.CONNECT$^{\text{TM}}$ [26].

In a further step the low fidelity e-motor model will replaced by a separated power motor controller (the four-quadrant converter) and a physical e-motor model. This step is much more challenging because the bandwidth of the phase signals which are exchanged between inverter and e-motor goes up to 1 kHz. Thus, the coupling frequency of two the subsystems must be even higher, in order to exchange a proper sinusoidal signal. Authors will investigate this issue. More details regarding the coupling frequency can be found in [22].

Moreover, it is also planned to run a real-time co-simulation. Thus, the VCU will be compiled and executed in a virtual environment (INtime) while the other subsystems will be executed in a non-virtual environment (Windows). It is required that all subsystems are RT capable. The basic requirement for real time capability is, that the computation time is lower than the solver step size at each iteration. More information concerning real-time co-simulation can be found in [27].

TABLE III COSIMULATION SOLVER AND SAMPLE RATE SETTINGS

Co-Simulation Settings			
System		***Sample Time***	***Solver***
UBM	*BBC*	0.01 [s]	ODE1 (Euler)
	Hydraulic Brake	0.001 [s]	ODE14x (Extrapolation)
VM		0.01 [s]	Standard
Comunication		0.01 [s]	

REFERENCES

[1] A. Emadi, Young Joo Lee, and K. Rajashekara, 'Power Electronics and Motor Drives in Electric, Hybrid Electric, and Plug-In Hybrid Electric Vehicles', *IEEE Trans. Ind. Electron.*, vol. 55, no. 6, pp. 2237–2245, Jun. 2008.

[2] B. Bilgin and A. Emadi, 'Electric Motors in Electrified Transportation: A step toward achieving a sustainable and highly efficient transportation system', *IEEE Power Electron. Mag.*, vol. 1, no. 2, pp. 10–17, Jun. 2014.

[3] A. Walker, M. Galea, C. Gerada, A. Mebarki, and D. Gerada, 'A topology selection consideration of electrical machines for traction applications: towards the FreedomCar 2020 targets', p. 10.

[4] L. Pugi, F. Grasso, M. Pratesi, M. Cipriani, and A. Bartolomei, 'Design and preliminary performance evaluation of a four wheeled vehicle with degraded adhesion conditions', *Int. J. Electr. Hybrid Veh.*, vol. 9, no. 1, p. 1, 2017.

[5] J. de Santiago *et al.*, 'Electrical Motor Drivelines in Commercial All-Electric Vehicles: A Review', *IEEE Trans. Veh. Technol.*, vol. 61, no. 2, pp. 475–484, Feb. 2012.

[6] M. T. Von Srbik and R. F. Martinez-Botas, 'Vehicle optimisation for regenerative brake energy maximisation', in *Sustainable Vehicle Technologies*, Elsevier, 2012, pp. 165–174.

[7] J. A. A. Hartley, R. G. McLellan, J. Richmond, A. J. Day, and I. F. Campean, 'Regenerative braking system evaluation on a full electric vehicle', in *Innovations in Fuel Economy and Sustainable Road Transport*, Elsevier, 2011, pp. 73–86.

[8] L. Berzi, M. Delogu, and M. Pierini, 'Development of driving cycles for electric vehicles in the context of the city of Florence', *Transp. Res. Part Transp. Environ.*, vol. 47, pp. 299–322, Aug. 2016.

[9] C. Qiu and G. Wang, 'New evaluation methodology of regenerative braking contribution to energy efficiency improvement of electric vehicles', *Energy Convers. Manag.*, vol. 119, pp. 389–398, Jul. 2016.

[10] R. Conti, E. Galardi, E. Meli, D. Nocciolini, L. Pugi, and A. Rindi, 'Energy and wear optimisation of train longitudinal dynamics and of traction and braking systems', *Veh. Syst. Dyn.*, vol. 53, no. 5, pp. 651–671, May 2015.

[11] T. Grigoratos and G. Martini, 'Brake wear particle emissions: a review', *Environ. Sci. Pollut. Res.*, vol. 22, no. 4, pp. 2491–2504, Feb. 2015.

[12] P. Tawadros, N. Zhang, and A. Boretti, 'Integration and performance of regenerative braking and energy recovery technologies in vehicles', in *Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance*, Elsevier, 2014, pp. 541–563.

[13] 'Homepage - Obelics | Obelics'. [Online]. Available: https://obelics.eu/. [Accessed: 17-Apr-2019].

[14] L. Pugi, M. Malvezzi, S. Papini, and S. Tesi, 'Simulation of braking performance: The AnsaldoBreda EMU V250 application', p. 13.

[15] K. T. Chau, 'Pure electric vehicles', in *Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance*, Elsevier, 2014, pp. 655–684.

[16] C. Satzger, R. de Castro, A. Knoblach, and J. Brembeck, 'Design and validation of an MPC-based torque blending and wheel slip control strategy', in *2016 IEEE Intelligent Vehicles Symposium (IV)*, Gotenburg, Sweden, 2016, pp. 514–520.

[17] C. Satzger and R. de Castro, 'Combined wheel-slip control and torque blending using MPC', in *2014 International Conference on Connected Vehicles and Expo (ICCVE)*, Vienna, Austria, 2014, pp. 618–624.

[18] C. Lv, H. Wang, and D. Cao, 'Brake-Blending Control of EVs', in *Modeling, Dynamics and Control of Electrified Vehicles*, Elsevier, 2018, pp. 275–308.

[19] L. Berzi, T. Favilli, E. Locorotondo, M. Pierini, and L. Pugi, 'Real Time Models of Automotive Mechatronics Systems: Verifications on "Toy Models"', in *Advances in Italian Mechanism Science*, vol. 68, G. Carbone and A. Gasparetto, Eds. Cham: Springer International Publishing, 2019, pp. 141–148.

[20] L. Pugi, T. Favilli, L. Berzi, M. Pierini, and E. Locorotondo, 'Application of Regenerative Braking on Electric Vehicles', p. 6.

[21] 'The Distributed Co-Simulation Protocol for the Integration of Real-Time Systems and Simulation Environments', in *Proceedings of the 50th Computer Simulation Conference*, University of Bordeaux, Bordeaux, France, 2018.

[22] M. Benedikt, D. Watzenig, J. Zehetner, and A. Hofer, 'MACRO-STEP-SIZE SELECTION AND MONITORING OF THE COUPLING ERROR FOR WEAK COUPLED SUBSYSTEMS IN THE FREQUENCY-DOMAIN', p. 12.

[23] B. Allotta and L. Pugi, *Meccatronica: azionamenti elettrici ed oleodinamici*. Bologna: Esculapio, 2016.

[24] S. Murata, 'Innovation by in-wheel-motor drive unit', *Veh. Syst. Dyn.*, vol. 50, no. 6, pp. 807–830, Jun. 2012.

[25] Junjun Deng, Siqi Li, Sideng Hu, C. C. Mi, and Ruiqing Ma, 'Design Methodology of LLC Resonant Converters for Electric Vehicle Battery Chargers', *IEEE Trans. Veh. Technol.*, vol. 63, no. 4, pp. 1581–1592, May 2014.

[26] 'Model.CONNECT$^{\text{TM}}$ - Model.CONNECT$^{\text{TM}}$ - IODP Portfolio', *AVL*. [Online]. Available: https://www.avl.com. [Accessed: 24-Apr-2019].

[27] S. Georg Stettinger, M. Martin Benedikt, B. Norbert Thek, and Josef Zehetner, *Computational methods for coupled problems in science and engineering V*. Barcelona: International Center for Numerical Methods in Engineering, 2013.