A Test Framework for the Co-simulation of Electric Powertrains and Vehicle Dynamics

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EXTENDED ABSTRACT

1 Introduction

Automobiles are complex engineering systems composed of a large array of elements with different physical properties and behaviour, including mechanical components, electronic control units (ECUs), and hydraulic devices, among others. System-level simulation is currently a requirement in the development of new vehicle components and technologies; the dynamics behaviour of each subsystem in the overall assembly must be considered in the context of its interaction with the rest of components. Moreover, real-time (RT) performance is demanded at several steps of the development cycle, e.g., in Human- and Hardware-in-the-Loop (HiL) benches used in system-level safety and component reliability tests.

Co-simulation [1] is an increasingly popular approach that makes it possible to perform system-level analyses in an effective and modular way. In a co-simulation setup, the dynamics of each subsystem is dealt with using a dedicated solver, especially adapted to its physical properties and behaviour. The communication between the different solvers is limited to the exchange of certain coupling variables at time-discrete synchronization points. Co-simulation enables the use of target-specific, efficient solution methods in complex practical applications, in which the use of monolithic simulation tools would often lead to performance trade-offs. It also simplifies the distribution of the computational workload between several processing units. Additionally, the exchange of coupling variables between solvers takes place through a minimal interface that hides the implementation details of each subsystem, which represents an attractive feature in industrial environments where the protection of intellectual property is an issue. On the other hand, co-simulation also brings about the need to coordinate and keep stable the numerical integration of the subsystems. The time-discrete exchange of information at the coupling interface can introduce discontinuities and delays in this process that may in turn result in inaccurate results or even the instability of the simulation. Iterative co-simulation schemes, that involve the repetition of the integration step of one or more subsystems in a predictor-corrector fashion, are a way to mitigate this problem [2]. These methods, however, cannot be used with subsystems that do not allow retaking integration steps. This limitation may be motivated by the need to achieve RT performance; physical components in HiL setups can also prevent the use of iterative algorithms. In these cases, non-iterative, explicit co-simulation methods must be used. A variety of methods to keep non-iterative co-simulation stable and accurate can be found in the literature. Coupling variables can be extrapolated using polynomial approximations [3]; it is also possible to monitor and correct the system energy exchanged at the interface to this end [4, 5]. Each of the proposed methods has different requirements to operate and it is difficult to predict which of them will deliver the best results in a given application.

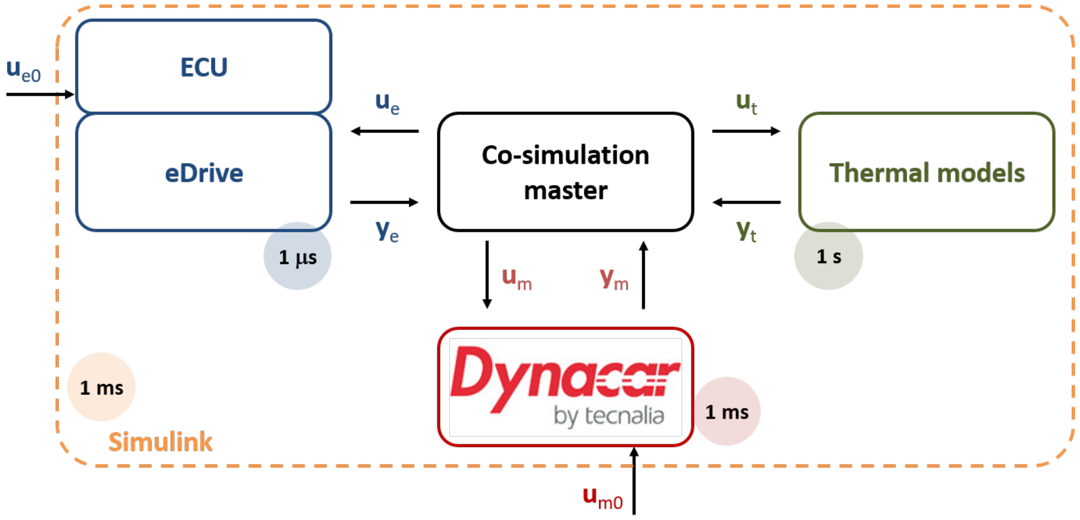

Figure 1: Scheme of the proposed co-simulation framework. Inputs and outputs of each subsystem are denoted by **u** and **y**, respectively.

2 Application case

The research reported in this document is motivated by the need to evaluate the behaviour and performance of new electronic components for the powertrain of electric vehicles (EVs) based on wide gap band (WGB) power electronic technologies currently under development. The use of co-simulation environments allows realistic system-level simulations of the vehicle behaviour during critical manoeuvres and endurance tests from the early stages of the development cycle. The obtained results can in turn be used to streamline the design of the new components before actual prototypes are manufactured. In a second stage, the new electronic components will be assessed using HiL test benches. The evaluation of these new powertrain elements requires a realistic modelling of their interaction with the vehicle dynamics. Thermal effects in the electronic components must also be taken into consideration, as temperature changes affect their performance.

Figure 1 shows the initial implementation of a multiphysics co-simulation environment that handles the coupled dynamics of the mechanical, electronics, and thermal subsystems of an EV. The purpose of this environment is to simplify the performance evaluation of different stabilization algorithms in the explicit, multirate co-simulation of representative models of the vehicle subsystems. The vehicle dynamics is solved using the multibody system dynamics simulation tool Dynacar, developed jointly with Tecnalia.

The power electronics model includes a 300-V Li-ion battery, a three-phase inverter (IGBTs and diodes), a gate-driver control to activate and deactivate the set of IGBTs, and a three-phase surface-mounted permanent magnet synchronous motor (SPM), that represents the in-wheel motor mounted on the vehicle. The inverter feeds the motor with a pulsating voltage, which is filtered by the motor inductance and generates a quasi-sinusoidal current in each motor phase. A voltage-behind-reactance (VBR) model is used to describe the motors. This model includes the Joule losses at the stator coils, the equivalent inductance of the magnetic field of the rotor and a back-electromotive force proportional to magnet flux, stator currents, and speed. The three motor phases are arranged following a wye connection [6]. The gate-driver control applies a Space Vector Pulse Width Modulation (SVPWM) to the IGBTs in the inverter [7]. Thermal equivalent circuits will be used to describe the power generation and dissipation characteristics of the electronic components.

The co-simulation master block is responsible for managing the exchange of coupling variables, synchronizing the numerical integration of the subsystems, and executing the stabilization algorithms. The environment has been implemented in Simulink; the blocks that represent the subsystems can contain Simulink models or externally compiled libraries.

The preliminary simulation tool in Fig. 1 will be the basis for the development of a RT co-simulation platform that can be used in production environments such as HiL test benches.

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