Chapter 10
Real-Time Hardware-in-the-Loop in Railway: Simulations for Testing Control Software of Electromechanical Train Components

Silvio Baccari
University of Sannio, Italy

Giulio Cammeo
AnsaldoBreda, Italy

Christian Dufour
Opal-RT Technologies, Canada

Luigi Iannelli
University of Sannio, Italy

Vincenzo Mungiguerra
AnsaldoBreda, Italy

Mario Porzio
AnsaldoBreda, Italy

Gabriella Reale
University of Sannio, Italy

Francesco Vasca
University of Sannio, Italy

ABSTRACT
The increasing complexity of modern ground vehicles is making crucial the role of control for improving energetic efficiency, comfort and performance. At the same time, the control software must be frequently updated in order to let the vehicle respond safely and efficiently within more sophisticated environments and to optimize the operations when new vehicle components are integrated. In this framework real-time hardware-in-the-loop simulations represent a fundamental tool for supporting the verification and validation processes of the control software and hardware. In this chapter a railway case study will be presented. The mathematical models of the most relevant electromechanical components of the vehicle powertrain are presented: the pantograph connected to an ideal overhead line with continuous voltage; the electrical components of a pre-charge circuit, the line filter and the braking chopper; the three-phase voltage source inverter and the induction motor; and, finally, the mechanical transmission system, including its interactions with the rail. Then the issues related to the real-time simulation of the locomotive components models are discussed, concentrating on challenges related to the stiff nature of the dynamic equations and on their numerical integration by combining field programmable gate array
Real-Time Hardware-in-the-Loop

INTRODUCTION

Hardware-in-the-loop (HIL) techniques are widely used in several engineering fields for testing, verification and validation of specific components designed to perform dedicated functions into complex environments. In our framework, the electronic control unit (ECU), as regards its functionalities dedicated to the control of electromechanical components of a typical train traction architecture, represents the device under test. The ECU is composed of a hardware device and its firmware and it is inserted into the loop completed with mathematical models emulating other parts of the equipment under control. In particular the models are implemented through software programs and corresponding processing units able to provide in real-time the electrical stimuli needed to partially or fully test and exercise the ECU. In this way the ECU and the control algorithms coded in it respond to the simulated signals so as they were operating in the real system under control.

The benefits of real-time HIL systems are manifold. HIL systems allow the testing of new ECUs so as they support the verification, validation and regression testing processes of the control software. Replacing (part of) the real equipment under control with computers running software simulations greatly reduces the size and complexity of applications and increases the flexibility and rate of running of different tests and scenarios. Obviously, this also means faster procedures for the calibration and the maintenance of the control software. Moreover HIL tests can be done without damaging equipment or endangering lives, then determining an improvement in term of costs, duration, feasibility and security.

Since several decades real-time HIL simulations have been applied to transportation systems, traditionally in the aerospace and automotive fields. More recently this technique has shown its potentialities also for railway systems (Terwiesch, et al., 1999; Dufour, et al., 2008; Allegre, et al., 2010) and in perspective it seems useful for supporting the analysis of many other railway control problems (Goodall, 2011). In fact, different railway on board subsystems can be effectively tested and validated through a HIL platform that emulates the behavior of the vehicle. For instance, odometry, anti-skid and braking functionalities could be tested through HIL (Pugi, et al., 2005a; Pugi, et al., 2005b). The same approach can be used also for investigating complex phenomena like adhesion between the rail and the wheel (Malvezzi, et al., 2008) or the interaction between the pantograph and the catenary (Collina, et al., 2004; Facchinetti and Mauri, 2009). The HIL technology has been also successfully applied for testing critical subsystems dealing with the train protection and the communication with interlocking systems (Di Tommaso, et al., 2005). In those cases the platform simulates sequences of real events aimed to test the correct behavior of safety critical railway control systems. With respect to traction subsystems, such applications need a different kind of models, particularly focused on describing temporal relations (concurrency, deadlock, etc.) rather than physical behaviors.

In this chapter we concentrate on real-time HIL simulations for testing the control software of the ECU dedicated to electromechanical powertrain components. The propulsion system, with its electrical and mechanical components and its interactions with the management transportation system, represents an interesting case-study.