Tutorial Title

Hardware-in-the-Loop Systems for Power Electronics Engineers: From Theory to Applications

Instructor Team

Team Chair: Bryan Lieblick, Plexim Inc.
Co-Speakers: Arnab Acharya, Arizona State University (ASU)

Abstract

<p>Real-time embedded systems such as microprocessors and FPGAs are a key component of modern power conversion systems. The embedded systems implement sophisticated control algorithms to ensure reliability under stringent operational requirements, particularly under extreme conditions. Engineers often must implement and test the embedded control logic without the physical power converter due to parallel development timelines and time-to-market pressures.</p><p>Hardware-in-the-loop (HIL) systems are increasingly used in the design and validation of complex embedded real-time systems to address these concerns. Dynamic models of the power converter are implemented on a specialized digital real-time simulator (DRTS). The controller is connected to the DRTS through electrical signal interfaces representing feedback from the virtual plant, such that the DRTS mimics the behavior of the power stage. The fast dynamics and non-linear characteristics of power conversion systems require special modeling techniques for accurate real-time models. Technology drivers are pushing the switching frequency into the MHz range and reducing the electrical time constants further. A high-fidelity model of the converter, fast update rate for calculations, and low loop-back latency are required for meaningful simulation models.</p><p>This tutorial aims to equip participants with a deep understanding of HIL systems, enabling them to navigate challenges, leverage emerging technologies, and effectively apply these advancements in real-world power electronics applications. A key focus of the tutorial is on the critical importance of understanding simulation algorithms and switch models within the HIL simulation. This approach empowers users to optimize their simulation tool chain, extract maximum fidelity from their models, and gain a deeper understanding of the simulation results. The tutorial has three main sections.</p><p>The first section is an introduction to fundamental HIL concepts and applications including a discussion of hard real-time systems and a comparison of different computational technologies. We explore the impact of market forces, such as Silicon Carbide (SiC) and Gallium Nitride (GaN), on shaping the next generation of HIL requirements. This section serves as a foundation for understanding the evolving landscape of HIL technologies and the hurdles that must be overcome in their implementation for power electronics. </p><p>The second section of this tutorial, focused on theory, addresses numerical modeling of power converters in the HIL context. The discussion consists of system modeling: spanning continuous and discrete simulation methods, the impact of simulation step size, loop-back latency, and multi-rate systems. Next attendees will learn about modeling approaches for electrical switches. This will include an introduction to sub-cycle average switch models, distinctions between ideal and non-ideal switch models, and specialized modeling techniques for high-frequency DC/DC converters.</p><p>The third section is an interactive demonstration translating the theoretical foundations into practical application, showcasing the implementation of HIL systems within real-world

industry scenarios. This includes a detailed walk-through of a system model, emphasizing various switch modeling approaches within the application. Participants gain insights into system timing, discretization times for different sub-systems, HIL I/O configuration, and control system deployment. This final section serves as a bridge between theory and practical application, empowering participants to effectively leverage HIL systems in their specific power electronics applications.</p>

Instructor Team Biographies

Bryan Lieblick:

Bryan Lieblick is a Real-Time Simulation Engineer at Plexim Inc., where he has been contributing since 2018. He specializes in the development of simulation models and controls for power electronic applications with a focus on real-time systems. Mr. Lieblick plays a key role in ensuring the success of Plexim Inc.'s customers through custom engineering services and technical support.

Before joining Plexim Inc., Mr. Lieblick served as a Senior Network Planning and Applications Engineer at AMSC. During his tenure, he conducted technical studies and modeling of power electronics systems, with a focus on renewable, industrial, and utility applications. His expertise also encompassed HIL studies of grid connected power converters. Prior to AMSC he specialized in power systems consulting at ABB.

Mr. Lieblick holds a Bachelor's degree in Electrical Engineering from Georgia Tech and a Master of Science in Engineering from Arizona State University.

Arnab Acharya:

Arnab is a power electronics enthusiast with 2 years of experience with Mercedes-Benz Research and Development India, Bengaluru. He also has an internship experience with National Renewable Energy Lab (NREL), Colorado. Arnab received his master's in electrical engineering (MS) from IIT Kharagpur with a specialization in power electronics. He has been actively publishing articles and presenting his research in top IEEE conferences. He has conducted a professional education seminar on grid connected PV inverter system design and considerations in APEC 2024 at Long Beach.

Arnab is currently pursuing his doctoral studies on grid forming inverters and renewable grid integration at Arizona State University. He has been an active member of professional bodies like IEEE PES and PELS societies.