Tutorial Proposal

1. Tutorial Title

Power Electronics Modelling for Real-Time Simulation

2. Instructor Team: name(s), affiliation(s), and contact information

Dr.-Ing. Giovanni De Carne, Karlsruhe Institute of Technology, Karlsruhe, Germany, email: Giovanni.carne@kit.edu

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3. Abstract (No more than 500 words. Accepted abstract will be published through the conference website, program, and proceedings.)

Digital Real Time Simulators (DRTS) are powerful tools that enable the connection between the digital and real world. Large and complex systems, such as electrical grids, can be simulated in real time, where the digital simulators can compute their model solutions with relatively small time steps (10~50µs or below). These small time steps permit to interface the simulated electrical networks with real hardware, such as grid controllers or power devices, with reasonable time fidelity and response. Interfacing these simulators with external devices by means of sensors and digital or analog communication, such as in Hardware-In-the-Loop (HIL) testing, allows to exchange digital- or hardware-measured variables between the digital and real world.

While digital real time simulation has clear potential to flexibly test any hardware in realistically simulated grid conditions, its limitations must be considered. On the opposite of off-line simulations, where a larger size of the simulated network makes the simulation computations only slower, DRTSs must respect hard real time constraints. These constraints mean that the simulated system solution shall be delivered within the desired time step and any overrun results in the interruption and failure of the simulation. As a consequence, the size of the simulated system must stay relatively small to meet computational timing constraints. Increasing the simulation details, e.g. power electronics switches or high-order generator equations, decreases the system scale, that can be solved in a certain time step. These restrictions are exacerbated with simulation of switching power electronics due to computational cost of solving models of their non-linear nature.

This tutorial's goal is to train the researchers approaching digital real time simulation in performing computational time-efficient and accurate simulations of electrical networks, and in particular of power electronics-based ones. The tutorial is structured with a system-to-component level approach. In the first section, we will provide guidelines to the modelling of grid connected converters so to minimize the computational effort while maintaining the accuracy required by the specific design or analysis objective. In this section we will focus on test scenarios (e.g. primary frequency regulation) that require the modelling of large power systems with a high number of converters. Those models target a time step of a few tens of microsecond.

While in the first section we will mainly focus on averaged converters models and control representation, in the second section we will review well known techniques for the switching representation of power converters, and we will analyze how the different modelling approach affect the computational effort. We will then focus on scenarios that require a switching representation of power converters. The focus will still be on analysis and systems that require a microseconds level time resolution.

In the third section we will then analyze how power converters can be modelled to achieve switching representations while targeting time steps below one microsecond. We will review the benefit and limits of dedicated execution approaches as well as of the use of Field Programmable Gate Array (FPGA) based platforms. The focus in this case is the simulation of microgrids scenarios with high frequency power converters (50-200kHz).

During the tutorial we will make large use of code examples and exercise. The tutorial will take an agnostic approach in respects to commercial solutions, all examples will be based on open-source software and will be provided to the attendees. While some of the code examples presented could be used directly for real time simulation also on FPGAs we are aware that most of the attendees will use commercial platforms more readily available in their engineering and research activities. The goal of the provided examples and exercise is to highlight the fundamental modelling choices that exist for simulation of power converters-based power systems and provide informed guidelines that the attendees can then use with commercial tools.

4. Tutorial Outline (Outline shall only define the topics and subtopics. No detailed descriptions please. Time allocation and instructor breakdown by topics is recommended.)

The tutorial will move with a from-system-to-component approach, where we will start to describe the modelling in real time simulator of power electronics converter for power system applications. Following we move more to a component level, where the impact of power electronics modelling is analyzed for FPGA computing applications. Finally, a new software and FPGA-based development environment for simulation solver creation, ORTiS Solver Codegen, will be introduced and its potentiality explained in details.

The overall structure of the tutorial can be summarized as follows:

- Modelling approaches for real time simulation in power systems: how to reduce computational effort preserving simulation accuracy. (60 minutes + 15 minutes Q&A and break). Dr.-Ing. Giovanni De Carne
- Modelling approaches for switching representation of power converters: possibilities and trade-off. (45 minutes) Prof. Andrea Benigni

- High switching frequency power converter modelling: execution approach and architectures (45 minutes + 15 minutes Q&A) Dr. Matthew Milton

5. Lecture Style and Requirements (Briefly describe the tutorial format, which may include traditional lecture, software/hardware demonstration, interactive audience polls/quizzes, worksheets, discussion, etc. Note any equipment or space requirements beyond a laptop and projector. Also list the targeted audience and tutorial difficulty level, including any pre-requisite knowledge.)

The tutorial will consist of 40% frontal lecture, 40% of simulations, and 20% of interactive discussion. The simulation software will be provided during the tutorial lecture, to be downloaded by participants. Simple Matlab/Simulink licences will be needed for the correct performance of the exercise. The simulations will be also carried out by the lecturers on projector as part of the lecture, in order to confront the aforementioned theory with the practice. At the end of each block, a 15 minutes Q&A section will take place, where the participants will be invited to constructive discussions.

6. Instructor Biography (No more than 200 words for each person. Each biography shall include the qualifications most relevant to the proposal. Past tutorial/teaching experience and outcome can be highlighted. External website link can be included but may not be reviewed.)

Giovanni De Carne (S'14-M'17-SM'21) received the M.Sc. degree in electrical engineering

from the Polytechnic University of Bari, Italy, in 2013, and the Ph.D. degree from the Chair of Power Electronics, Kiel University, Germany, in 2018.

He is currently the head of the “Real Time System Integration” Group and head of the "Power Hardware In the Loop Lab" at the Institute for Technical Physics at the Karlsruhe Institute of Technology.

He has authored/coauthored more than 60 peer-reviewed scientific papers. His research interests include power electronics transformers, real time modelling, and power- and hardware-in-the-loop testing.

He is an Associate Editor of the IEEE Industrial Electronics Magazine and IEEE Open Journal of Power Electronics. He held several tutorials at international conferences (ECCE, ECCE Asia, PowerTech, ISGT Europe) on the Smart Transformer applications topic. He has organized an international ECPE workshop on Hardware In the Loop in 2021 with large industrial involvment, and he is the Technical Committee Chairman for the IEEE 2022 PEDG conference, to be held in June 2022 in Kiel, Germany.

Matthew Milton received the M.S. and Ph.D. degrees in electrical engineering from University of South Carolina, Columbia, SC, USA, in 2016 and 2021, respectively.

He is currently a Post-Doctoral Fellow Researcher with the department of Electrical Engineering at University of South Carolina, Columbia, SC, USA. His present research interests include real-time software- and FPGA-based simulation approaches and tool development for power electronic and energy system applications, such as in control, digital twinning, and hardware-in-the-loop testing.

Andrea Benigni (S'09-M'14-SM'20) received the B.Sc. and M.Sc. degrees from Politecnico di Milano, Milano, Italy, in 2005 and 2008, respectively, and the Ph.D. degree from RWTH-Aachen University, Aachen, Germany, in 2013. From 2014 to 2019, he was an Assistant Professor with the Department of Electrical Engineering, University of South Carolina, Columbia, SC, USA. Since 2019 he is a full professor at RWTH-Aachen and director of the "Institute of Energy and Climate Research: Energy Systems Engineering (IEK-10)" at the Juelich research center. Prof Benigni works in the field of real-time simulation and hardware in the loop testing since more than ten years, he published several papers on the use of those technologies and on the definition of parallelization algorithms that allow nanosecond resolutions in the real-time simulation of power electronics systems. He is the general chair of the 1st International workshop on "Open Source Modelling and Simulation of Energy Systems" (OSMSES 2022) and chair of the technical committee on Smart Grid of the IEEE Industrial Electronics Society. Through the years he has organized several special sessions at IECON, ISIE and INDIN and served as publicity chair for the IEEE Electric Ship Technologies Symposium (ESTS 2019).