Tutorial proposal

Title: Methods and Tools for Validating Cyber-Physical Energy Systems

1. **Presenter(s)** *(Title, name, affiliation, email address and personal website (if any)***:**

- Prof. Dr. Antonello Monti, E.ON Energy Research Center. RWTH Aachen, Aachen, Germany amonti@eonerc.rwth-aachen.de, link to personal website
- Prof. Ferdinanda Ponci, E.ON Energy Research Center. RWTH Aachen, Aachen, Germany fponci@eonerc.rwth-aachen.de, link to personal website
- Dr. Marco Cupelli, E.ON Energy Research Center. RWTH Aachen, Aachen, Germany mcupelli@eonerc.rwth-aachen.de, link to personal website
- Privatdoz. Dr. Thomas I. Strasser, AIT Austrian Institute of Technology, Vienna, Austria thomas.i.strasser@ieee.org, link to personal website

2. **Brief description** *(What you are going to present?)***:**

Future power systems have to integrate a higher amount of distributed, renewable energy resources to cope with a growing electricity demand, while at the same time trying to reduce emission of greenhouse gases. In addition, power system operators are nowadays confronted with further challenges due to the highly dynamic and stochastic behaviour of renewable generators (solar, wind, small hydro, etc.) and the need to integrate controllable loads (electric vehicles, smart buildings, energy storage systems, etc.). Furthermore, due to ongoing changes to framework conditions and regulatory rules, technology developments (development of new grid components and services) and the liberalization of energy markets, the resulting design and operation of the future electric energy system has to be modified.

Sophisticated (systems and component) design approaches, intelligent information and communication architectures, and distributed automation concepts provide ways to cope with the above-mentioned challenges and to turn the existing power system into an intelligent entity, that is, a "Cyber-Physical Energy System (CPES)" (also known as "Smart Grid"').

While reaping the benefits that come along with intelligent solutions, it is, however, expected that due to the considerably higher complexity of such solutions, validation and testing will play a significantly larger role in the development of future technology. As it stands, the first demonstration projects for smart grid technologies have been successfully completed; it follows that there is a high probability of key findings and achieved results being integrated in new and existing products, solutions and services of manufacturers and system integrators. Up until now, proper validation and testing methods and a suitably corresponding integrated Research Infrastructure (RI) for smart grids is neither fully available nor easily accessible which fulfils the following main requirements:

- A cyber-physical, multi-domain approach for analysing and validating CPES at the system level is today missing; existing methods are mainly focusing on the component level – system integration topics including analysis and evaluation are not yet addressed in a holistic manner.
- A holistic validation framework (incl. analysis and evaluation/benchmark criteria) and the corresponding RI with proper methods and tools needs to be developed.
- Harmonized and standardized evaluation procedures need to be developed.
- Well-educated professionals, engineers and researchers that understand smart grid systems in a cyber-physical manner need to be trained on a broad scale.

3. **Outline** *(How you are going to use 2 hrs time to present your tutorial?)***:**

The aim of this tutorial is to tackle the above-mentioned requirements by introducing validation methods and tools for validating CPES. The tutorial provides an overview of a holistic validation approach, a formal validation description method for CPES and corresponding simulation and laboratory based validation methods/tools.

The tutorial is structured into the following main parts:

1. Introduction into CPES (about 10 min)
2. Validation and testing approaches (about 30 min)
   - Requirements for testing CPES
   - Holistic validation approach
   - Validation description method for CPES
   - Challenges related to uncertainty management
   - Definition of interoperability
3. Methods and tools (about 60 min)
   - Real-time simulation for electric systems
   - Co-simulation of power systems and ICT technology
   - Application of Hardware-in-the-Loop
   - Coupling of distributed real-time simulation systems
   - Distributed lab-based testing of power systems
4. Application fields and examples (about 20 min)

4. Publications *(Your publications relevant to the tutorial)*:

[1] J. Wang, Y. Song, W. Li, J. Guo, A. Monti, "Development of a Universal Platform for Hardware In-the-Loop Testing of Microgrids," IEEE Trans. Ind. Inform., vol. 10, no. 4, pp. 2154-2165, 2014.

[2] M. Manbachi, Moein, S., Abhinav, H. Farhangi, A. Monti, A. Palizban, F. Ponci, "Real-Time Co-Simulation Platform for Smart Grid Volt-VAR Optimization Using IEC 61850," IEEE Trans. Ind. Inform., vol. 12, no. 4, pp. 1392-1402, 2016.

[3] T. Strasser et al. "Towards holistic power distribution system validation and testing-an overview and discussion of different possibilities," e & i Elektrot. und Informationst., vol. 134, no. 1, 2017.

[4] T. Strasser et al. "A Review of Architectures and Concepts for Intelligence in Future Electric Energy Systems," IEEE Transactions on Industrial Electronics, vol. 62, no. 4, pp. 2424-2438, 2015.

[5] F. Ponci, A. Sadu, R. Uhl, M. Mirz, A. Angioni and A. Monti, "Instrumentation and measurement testing in the real-time lab for automation of complex power systems," in IEEE Instrumentation & Measurement Magazine, vol. 21, no. 1, pp. 17-24, February 2018.

[6] P. Jamborsalamati, A. Sadu, F. Ponci and A. Monti, "A flexible HiL testing platform for performance evaluation of IEC 61850-based protection schemes," 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, 2016, pp. 1-5.

[7] W. Li, M. Ferdowsi, M. Stevic, A. Monti and F. Ponci, "Cosimulation for Smart Grid Communications," in IEEE Transactions on Industrial Informatics, vol. 10, no. 4, pp. 2374-2384, Nov. 2014

5. Presenter's biography *(IEEE style)*:

Antonello Monti (SM) received his M.Sc degree (summa cum laude) and his PhD in Electrical Engineering from Politecnico di Milano, Italy in 1989 and 1994 respectively. He started his career in Ansaldo Industria and then moved in 1995 to Politecnico di Milano as Assistant Professor. In 2000 he joined the Department of Electrical Engineering of the University of South Carolina (USA) as Associate and then Full Professor. Since 2008 he is the director of the Institute for Automation of Complex Power System within the E.ON Energy Research Center at RWTH Aachen University. Dr. Monti is author or co-author of more than 300 peer-reviewed papers published in international Journals and in the proceedings of International conferences. He is a Senior Member of IEEE, Associate Editor of the IEEE System Journal, Associate Editor of IEEE Electrification Magazine, Member of the Editorial Board of the Elsevier Journal SEGAN and member of the founding board of the Springer Journal "Energy Informatics". Dr. Monti is the recipient of the 2017 IEEE Innovation in Societal Infrastructure Award.

Ferdinanda Ponci (M'00–SM'08) received the Ph.D. degree in electrical engineering from the Politecnico di Milano, Milan, Italy, in 2002. She was with the University of South Carolina, Columbia, SC, USA. In 2009, she joined the Institute for Automation of Complex Power Systems, E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany, where she is currently a Professor of monitoring and distributed control for power systems. Dr. Ponci is a member of the Administration Committee of the IEEE Instrumentation and Measurement Society and the society Liaison with the IEEE Women in Engineering.

Marco Cupelli (SM) received his Doctoral degree in Electrical Engineering from RWTH Aachen University and his Diploma degree in electrical engineering and business administration from Technische Universität Darmstadt. In 2009 he joined the Institute for Automation of Complex Power Systems, E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany, where he is currently the Division Head of Power Systems Control and Automation. He is an IEEE Senior Member of the IEEE Industrial Electronics Society (IES) and the IEEE Power and Energy Society (PES) where he is involved the P2030.10 working group. Furthermore, he is an active member of the European Union H2020 Bridge Initiative.

Thomas Strasser (M'09–SM'13) received a master's and a PhD degree as well as the venia docendi (Privatdozent) in the domain of automation from Vienna University of Technology. For several years, he has been a senior scientist in the Center for Energy of the AIT Austrian Institute of Technology. His main responsibilities involve strategic development of smart grid research projects and mentoring and advising junior scientist and PhD candidates. Strasser is also active as a senior lecturer (Privatdozent) at the Vienna University of Technology and has co-authored more than 170 scientific publications (editorials, book chapters, conference and journal papers) and was awarded 2 patents in his areas of interest. He is a senior member of the IEEE Systems, Man, and Cybernetics Society (SMCS), the IEEE Industrial Electronics Society (IES) and the IEEE Power and Energy Society (PES) where he is involved in several committees, task forces, and working groups. He is a member of the SMC Board of Governors (2018-2020) and member of the IES Administrative Committee (2018-2020)

6. Supporting IEEE IES Technical Committees (TC)

This tutorial is sponsored/supported by the IEEE IES TC on Smart Grids (TC-SG), the IEEE IES TC on Industrial Cyber-Physical Systems (TC-ICPS), and the IEEE IES Standards TC