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Tutorial Title

Understanding the stochasticity of harmonic impedances and injections for hosting capacity calculation

Speakers

Speaker 1	Name	Dr.-Ing. Amauri Martins Britto
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	Webpage/CV link/short bio	Amauri G. Martins-Britto (b. 1982, Brazil) received the B.Sc., M.Sc., and Ph.D. degrees in Electrical Engineering from the University of Brasília (UnB), Brazil, in 2005, 2017, and 2020, respectively. From 2005 to 2017, he worked as a Professional Engineer (P.Eng.) on industry projects involving power system grounding, cathodic protection, and electromagnetic interference between power lines and infrastructure. From 2018 to 2025, he served as a Professor with the Department of Electrical Engineering, UnB. He is currently a Researcher with KU Leuven and EnergyVille (ELECTA). His work concentrates on rigorous analytical and numerical modeling of overhead lines and underground cables on converter-rich grids, frequency- and time-domain parameter evaluation, electromagnetic transient (EMT) analysis, and advanced earth-return formulations. He develops open-source computational tools for parametric cable and line modeling, uncertainty quantification, and wideband impedance/admittance characterization, bridging theory and implementation with a strong emphasis on verification, reproducibility, and high-fidelity simulations. https://www.researchgate.net/profile/Amauri-Martins-Britto

Speaker 2	Name	Dr. -Ing. Jinwen Xiang
	Affiliation	KU Leuven – Etch EnergyVille
	Webpage/CV link/short bio	Jinwen Xiang received the B.S., M.Sc., and Ph.D. degrees in electrical engineering from Hunan University, China, and was a visiting Ph.D. student at the Technical University of Denmark. From 2023 to 2024, he was a control engineer at CRRC Zhuzhou Institute. Currently, he is a post-doctoral researcher with KU Leuven and the Energy Transmission Competence Hub (Etch) within EnergyVille, Belgium. His main areas of research are modeling and control of power electronics and their applications in transportation and power systems. https://www.kuleuven.be/wieiswie/en/person/00176372

Speaker 3	Name	Professor Hakan Ergun
	Affiliation	KU Leuven – Etch EnergyVille
	Webpage/CV link/short bio	Hakan Ergun, has obtained his MSc in electrical engineering at the Graz University of Technology (TU Graz) and his PhD in electrical engineering at KU Leuven, respectively. In the past he has been a post – doctoral researcher, and a research expert at KU Leuven / EnergyVille. Since 2024 he is an Associate Professor with KU Leuven and the Energy Transmission Competence Hub (Etch) within EnergyVille. His main research interest is to optimally develop and operate future energy networks for the renewable energy transition. He is the main developer of a number of open-source network modelling tools for optimal planning and operation of AC and DC grids, and stability and security constrained network operation. He is a senior member of IEEE and is an active member of CIGRE. https://www.kuleuven.be/wieiswie/en/person/00069734

Abstract

The European Green Deal mandates the transition to a climate-neutral European Union by 2050, placing large-scale industrial electrification at the core of the decarbonization strategy. In Belgium, industrial electricity consumption is expected to rise sharply by 2030 as electrification, carbon capture and storage (CCS), hydrogen production, and electrolysis become mainstream. This accelerated growth will impose unprecedented stress on both the national transmission grid and internal industrial power systems. Illustratively, industrial facilities that previously expanded their electrical demand gradually over several decades must now integrate comparable additional capacity within only a few years. Similar transitions across the national industrial landscape highlight the urgent need to identify and mitigate technical constraints that may slow down or obstruct electrification.

To meet climate targets, industrial actors are implementing a wide portfolio of measures including large-scale procurement of renewable electricity, electrification of steam and heat production, deployment of CCS, and development of new low-carbon processes. These shifts will significantly increase the deployment of high-power electrical drives and power-electronic converter systems. While these technologies are vital for decarbonization, they are also known sources of harmonic distortion, e.g., voltage and current components at multiples of the 50 Hz fundamental frequency. Increasing harmonic distortion can lead to reduced power quality, accelerated equipment degradation, elevated fire risk, and lower system reliability, ultimately affecting industrial productivity and competitiveness. As the number of converters grows, the risk of system-wide harmonic amplification becomes more pronounced, especially in grids undergoing structural changes such as increased underground cabling.

Ensuring the secure operation of the future transmission system will therefore require determining its harmonic hosting capacity, which is the maximum level of converter-driven harmonic pollution that can be safely accommodated. Addressing this challenge involves

closing several research gaps: developing detailed harmonic models of power-electronic converters that capture nonlinear behavior and frequency coupling; accurately characterizing uncertainty in cable and component parameters; and adopting systemwide modeling approaches that surpass the limitations of local or guideline-based methods.

This tutorial offers a structured overview of these challenges and the methodologies required to tackle them. It presents state-of-the-art modeling techniques, uncertainty quantification strategies, and stochastic assessment tools essential for understanding the harmonic behavior of power-electronic-dominated systems. All presented models and methods have been developed within the HARMONIC project, funded by the Belgian Energy Transition Funds, which aims to advance system-wide harmonic analysis and support the reliable integration of large-scale electrification technologies into industrial and transmission networks.

The tutorial is organized into three focused presentations: (1) Uncertainty quantification of harmonic power cable impedances, examining how parameter variability affects harmonic behavior; (2) Probability modelling of harmonic injections from power-electronic converters, analyzing how topology parameters and control structures shape stochastic harmonic distribution; and (3) Optimisation-based stochastic harmonic hosting capacity determination, providing a system-level framework to evaluate how much harmonic pollution the grid can reliably accommodate under uncertainty. Together, these presentations guide participants from component-level uncertainty to system-wide hosting capacity assessment, equipping them with the analytical tools needed to model various aspects of harmonics in the power system.