Tutorial Title:

High Voltage DC Transmission Systems: Developments, Opportunities and Challenges

Instructors Team:

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Abstract:

As large renewable power plants are often located far from consumption centres, integrating the power generated by these plants presents a significant challenge. For instance, the electrical outputs of these renewable plants may be in the form of DC or AC voltages with magnitudes and frequencies incompatible with the AC grids. Therefore, power electronics based interfaces are required to decouple the AC grids from the power plants, control active and reactive power exchange with the AC grid, and enable renewable power plants to ride through various AC and DC network faults.

Currently, state-of-the-art high-voltage direct current (HVDC) link technologies are based on voltage source converters. However, most operational HVDC transmission systems today still rely on thyristor-based, line-commutated current source converters, which offer lower semiconductor losses and higher power density due to the robustness and high current capability of thyristors in single-wafer capsules. Despite these advantages, thyristors introduce significant low-frequency harmonics into the AC side, necessitating large passive filters, and they do not allow for independent control of reactive power from the active or DC power injected into the AC network. This reliance on large passive components results in systems with substantial footprints. Self-commutated, voltage source converter-based HVDC transmission systems were developed to overcome the limitations of line-commutated current source converter-based HVDC systems.

This tutorial aims to clarify the advantages and disadvantages of different HVDC technologies, specifically line-commutated converters (LCC) and voltage source converters (VSC), in the broader context of large-scale power evacuation, HVAC grid support, and renewable power generation and integration. The latest modular multilevel converter topologies for HVDC systems. The interactions of current source and voltage source HVDC links with AC grids will be analysed, including the impacts of the controls and harmonics. AC and DC fault analysis for various HVDC technologies will be discussed, along with an exploration of DC grids, covering theoretical concepts, technology, control, fault management, DC/DC converters, and protection, with a particular emphasis on practical implementation and operational challenges. The talk is supported with simulation on MATLAB/SIMULINK software and practical prototype results.

Tutorial Outline:

- Basic HVDC configurations, main components, operating modes and control

- Line commutated converter, LCC rectifier converter, LCC inverter controller, extinction angle controller, and commutation failure
- VSC converter, modelling, PWM converter control and simulation
- The interactions of current source and voltage source HVDC links with AC grids will be analysed, including the impacts of the controls and harmonics
- The latest modular multilevel converter topologies for HVDC systems including hybrid topologies
- AC and DC faults analysis for different HVDC technologies
- DC protection strategies, including DC breakers (hybrid and mechanical)
- Generic DC grids with VSCs and LCCs
- Control strategies and technologies for DC grids including DC/DC converters (isolated and non-isolated), DC grid control
- HVDC plants around the world

Instructor Biography:

Add here the instructor biographies (max 250 words). Please, attach a picture of the instructors to the tutorial submission email.

Prof Khaled H. Ahmed

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Prof Khaled Ahmed received the BSc and MSc degrees from Alexandria University, Egypt in 2002 and 2004, respectively. He received the PhD degree in power electronics applications from the Electronic and Electrical Engineering Department, University of Strathclyde, UK, 2008. In 2011, he was appointed as a Lecturer in Power Electronics at the University of Aberdeen, and was promoted to Senior Lecturer in 2015. Currently, He is a Professor of power electronics at the University of Strathclyde, UK and the head of the Power Electronics, Drives and Energy Conversion Research Group. He has over 20 years of research experience in power electronics, renewable energy integration, solar energy systems, off-shore wind energy conversion systems, smart grids, DC/DC Converters and HVDC. He has won funding of £5.5 million as Primary and Co-Investigator on projects funded by EPSRC, the EU, KTP, the British Council, the Royal Society, the Carnegie Trust, the Scottish Funding Council, the Oil and Gas Technology Centre, and industry (Rolls-Royce, Scottish Power, and Scottish and Southern Energy). Recent funding included Orion Project (first Energy Hub in the UK), £630k, funded by BP, Shell, Equinor, Ithica Energy, SIC, and SSE, 2021-2024 and Horizon EU project, ‘Reliable and resilient AC & DC grid design to accelerate the integration of renewables across Europe’, £560k with 13 international academic and industrial partners 2022-2026 and Neom Ltd Project ‘Grid Code Development’ £748k, 2022-2023. He has supervised 25 PhD students; 15 have graduated and the others are ongoing. Prof. Ahmed has published over 180 technical papers in refereed journals and conferences, 1 book, 1 book chapter, and a patent (PCT/GB2017/051364). Total citations of 6531 and h-index of 32. Two of his journal papers are rated in the top 1% of those cited in the academic field of Engineering (Web of Science). He has led the design and delivery of continuing professional development (CPD) courses on HVDC, wind energy conversion systems for technology engineering team in Scottish Power, and Scottish and Southern Energy (SSE), UK. He is a senior member of the Institute of Electrical and Electronics Engineers (IEEE) Industrial Electronics and Power Electronics Societies, IET Fellow, Chartered Engineer, and Senior Fellow of Higher Education Academy (HEA). He serves as a Co Editor-in-Chief of Elsevier Alexandria Engineering Journal, and as an Associate Editor of IEEE Open Journal of the Industrial Electronics Society (OJIES), IET Generation, Transmission & Distribution and IEEE Access.

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Prof. Giovanni De Carne received the B.Sc. and M.Sc. degrees in electrical Engineering from the Polytechnic University of Bari, Italy, in 2011 and 2013, respectively, and the Ph.D. degree from the Chair of Power Electronics, Kiel University, Germany, in 2018. Prof. De Carne is currently W3 (full) professor at the Institute for Technical Physics at the Karlsruhe Institute of Technology, Karlsruhe, Germany, where he leads the “Real Time Systems for Energy Technologies” Group and the "Power Hardware In the Loop Lab". He is currently supervising PhD students, managing academic and industrial projects, and developing multi-MW Power Hardware In the Loop testing infrastructures for energy storage Systems and hydrogen-based drives. He has authored/coauthored more than 100 peer-reviewed scientific papers. His research interests include power electronics integration in power systems, solid state transformers, real time modelling, and power hardware in the loop. Prof. De Carne successfully hosted the IEEE eGrid2023 Workshop in Karlsruhe in October 2023 with high participation from industry. He is the chair of the “IEEE PES Task Force on Solid State Transformer Integration in Distribution Grids”. He has been technical program committee chair for several IEEE conferences, associate editor of the IEEE Open Journal of Power Electronics and several other IEEE and IET journals.