Design challenges of high-power converters with low switching frequencies

I. Abstract

This tutorial focuses on industrial high-power medium-voltage converters that use high-power medium-voltage devices like IGCTs and IEGTs. Such converters reach high power ratings (e.g. 10 – 30 MVA) with minimum quantity of switching devices. However, medium-voltage devices have typically high switching losses, which limit the switching frequency of converters at only several hundred Hertz. As a result, the optimization of the converter performance like the power capability, power quality and the control dynamics becomes challenging.

This tutorial discusses the design of such converters in three aspects: converter topology, modulation scheme and current controller. It should be noted that several special phenomena occur due to the low switching frequency, and they may lead to a significant performance degradation of the converter. In this tutorial, several modeling methodologies are introduced, which are explicitly developed to explore the mechanism of these special phenomena at low switching frequencies. Based on this, generalized design guidelines for the design and optimization are summarized, which have been developed, implemented and experimentally validated.

Comparative analysis of converters with low switching frequencies versus high switching frequencies will be conducted throughout the tutorial, since the latter ones are more familiar to most audience (as reference). Moreover, some design examples will be given.

II. Outline

- Introduction
  - Medium-voltage (MV) vs. low-voltage (LV) devices
  - MV vs. LV converters
  - Design challenges of MV converters
- Selection of multilevel (ML) topology
  - Benefit of ML topology for LV converters
  - Benefit of ML topology for MV converters
  - Design guidelines for selecting the level of ML topologies
- Modulation scheme
  - A precise and fast simulation tool for performance screenings of converters
  - Impact of modulation schemes on the power capability of converters
  - Design examples
- Current control loop
  - A precise and intuitive modeling concept for symmetric three-phase systems
  - Design concepts of multi-loop systems with extremely low sampling frequencies
  - Design examples
- Summary

III. Instructors

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IV. Biography

Shen Jie (M'05) was born in Shanghai, China. He received the bachelor degree from Shanghai Jiaotong University, China. Then he received the diploma and the doctoral degree both from RWTH Aachen University, Aachen, Germany, all in electrical engineering.

Since 2008 he is with GE Global Research Europe, Munich, Germany, where he is working on high-power multilevel converters for medium-voltage drives, renewable energy systems and Oil&Gas applications. As a system engineer, his research area includes multilevel topologies, controls and modulation schemes at low pulse-ratios, filters and transformerless concepts.

Stefan Schröder (S'98 – M'03– SM'10) was born in Cologne, Germany. He received the diploma and the doctoral degree both in electrical engineering from RWTH Aachen University, Aachen, Germany, in 1997 and 2003, respectively.

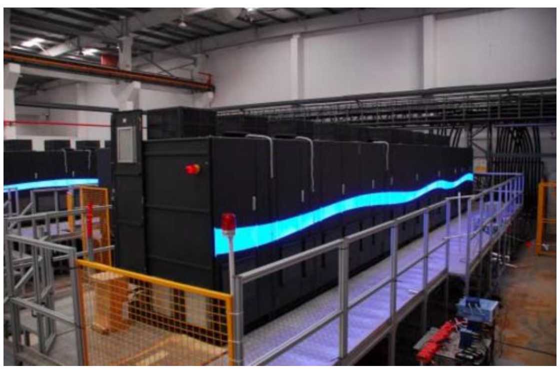
Since 1997, he has been a Research Associate at the Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University, where he was working on power electronic circuits and devices in particular on high-power semiconductors. Since July 2002, he has been Chief Engineer at the same institute responsible for the research in the fields of electrical drives, power electronic circuits and semiconductor devices. Since the beginning of 2005, he is with GE Global Research Europe, Munich, Germany, where he is working on power electronic applications with focus on high-power converters for medium-voltage drives and for renewable energy systems.

He has authored or coauthored over 40 published technical papers. Dr. Schröder is a member of VDE.

V. Authors' exemplary projects

(1) A 11 MW high-speed pumpback VSD tester with 1.25MW grid

(2) A 30MVA IGCT converter for Oil&Gas applications



(3) 2x27 MVA machine test bench with four-quadrat pumpback operations

(4) GE-MV6 series medium-voltage drive. Product video online available: http://www.youtube.com/watch?v=vt-Zdvtl618

VI. Relevant publications

1. J. Shen, S. Schröder, H. Stagge, and Rik W. De Doncker, "Impact of Modulation Schemes on the Power Capability of **High-Power Converters** with **Low Pulse Ratios**", *EPE'13 ECCE Europe 2013*, Sep. 3 – 5, Lille. Accepted for the publication on *Transactions on Power Electronics*.

2. J. Shen, S. Schröder, H. Stagge, and Rik W. De Doncker, "Design challenges of **industrial high-power converters** with **low pulse ratios**", published on *IEEE ECCE 2013*, Sep. 15 – 19, Denver.

3. S. Schröder, J. Shen, F. Zhang, K.L. Chen, L.G. Qin, and R. Zhang, "Test-Bench for **Very High Power** Variable Frequency Drives Working under Constrained Grid Conditions", *IEEE ECCE 2013*, Sep. 15 – 19, Denver.

4. Q. Y. Chen, J. Shen, H. Stagge, S. Schröder, and Rik W. De Doncker, "Damping Concepts of LCL Filter for a Multi-level Medium Voltage Adjustable Speed Drive with **Low Pulse Ratio**", *IEEE ECCE 2013*, Sep. 15 – 19, Denver.

5. J. Shen, "Modeling methodologies for analysis and synthesis for controls and modulation schemes for high.-power converters with low pulse ratios", Dissertation ISBN 978-3-942789-16-5, Verlag: E.ON Energy Research Center, RWTH Aachen University.

6. J. Shen, S. Schröder, H. Stagge, and Rik W. De Doncker, “A Fast and Precise Simulation Method for Performance Screening for **High Power Converter** Designs”, *IEEE Energy Conversion Congress & Exposition (ECCE) 2012*, Sep. 16 – 20, Raleigh, pp. 4418 – 4425.
7. J. Shen, S. Schröder, H. Stagge, and Rik W. De Doncker, “Precise Modeling and Analysis of DQ-Frame Current Controller for **High Power Converters** with **Low Pulse Ratio**”, *IEEE Energy Conversion Congress & Exposition (ECCE) 2012*, Sep. 16 – 20, Raleigh, pp. 61 – 68.
8. S. Schröder, P. Tenca, T. Geyer, P. Soldi, L. J. Garces, R. Zhang, T. Toma, and P. Bordignon, “Modular **High power** Shunt-Interleaved Drive System: A Realization up to **35 MW** for Oil and Gas Applications”, IEEE Trans. Ind. Applicat., vol. 46, no. 3, March/April 2010, pp. 821 – 830.
9. J. Shen, S. Schroeder, B. Qu, Y.Q. Zhang, L.G. Qin, K.L. Chen, F. Zhang, and R. Zhang, “Modulation Schemes for **a 30 MVA IGCT Converter** using NPC-H-Bridges”, submitted to *IEEE Energy Conversion Congress & Exposition (ECCE) 2014*.
10. J. Shen, S. Schroeder, B. Qu, L.G. Qin, Y. Liu, F. Zhang, K.L. Chen, and R. Zhang, “A High-Performance **27 MVA** Machine Test Bench Based on Multilevel **IGCT Converters**”, submitted to *IEEE Energy Conversion Congress & Exposition (ECCE) 2014*.
11. Q.Y. Chen, J. Shen, H. Stagge, S. Schroeder, and Rik W. De Doncker, “Performance Evaluation of Multiloop Current Control Strategies in LCL-Filtered **High-Power Converters** with **Low Pulse-Ratio**”, submitted to *IEEE Energy Conversion Congress & Exposition (ECCE) 2014*.