Control of Modular Multilevel Converters for Variable-Voltage Variable-Frequency Applications

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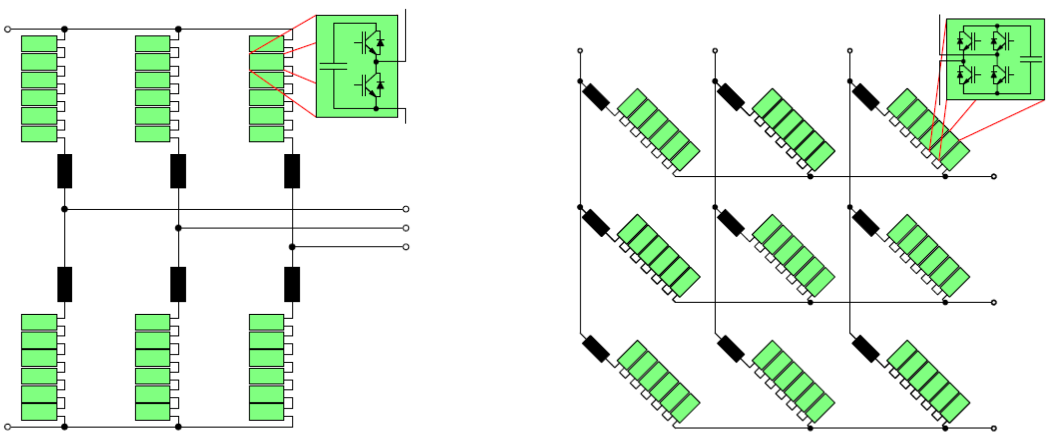
Scope and Benefits

Beside their exceptionally wide application in high-voltage direct-current systems, the modular multilevel converters are increasingly finding applications in various other fields. This tutorial focuses on modular multilevel converters (MMCs) and modular multilevel matrix converters (MMMCs) for applications that require a wide range of operating frequencies and converter voltages. Typical applications with such requirements are medium-voltage drives systems. While the superior voltage quality, the simple voltage scalability, and optional redundancy of both MMCs and MMMCs make them a preferable alternative, the high complexity of the system is a challenge that requires special control approaches to enable a stable operation. In this tutorial, the operation principle of these topologies will be explained, and the control strategies will be presented. An emphasis will be on the generalized control approach, proposed by our research group, which can be applied to both MMCs and MMMCs. Furthermore, the operation modes for stabilizing the operation at a wide range of frequencies will be explained. Besides the conventional operation modes, the quasi-two-level PWM operation, that is capable of reducing the module capacitance by more than one order of magnitude, will be presented as well.

After successfully attending this tutorial, the participants will understand

- the difference between MMCs with or without branch current control,
- the need to stabilize and balance the energies in the branches and modules
- a generic modelling and control approach for a large class of modular multilevel converters,
- how specific input or output frequencies affect the stability of the converters,
- how dedicated operating modes can deal with these obstacles and what their limitations are,
- and the benefits and limitations of novel, quasi-two-level PWM modes of operation for widely reduced module energy storage.



Modular Multilevel Converter (MMC) Modular Multilevel Matrix Converter (MMMC)

Fig. 1 Modular multilevel topologies considered in this tutorial.

Contents

Part 1 (9:30 – 11:00)

1. Motivation for MMCs and MMMCs
2. Introduction
    a. Description of topologies with examples of practical realizations
    b. Goals for the modulation, the control, and the operation modes
    c. Options for converter modelling (device based models and mathematical models in Plexim Plecs, state-space models for current control testing, models for branch energy control testing)
    d. Basic design process for module capacitors and semiconductor devices
3. Modulation
    a. Overview of the options and principles
    b. Principle and implementation of the multi-carrier modulator according to group of Prof. Akagi, e.g. [1], and the two-step sorting-based modulators, e.g. [2].

Part 2 (11:30 – 13:00)

4. Control
   (main focus on the generalized control approach according to [3-4])
    a. Control system description of the MMC and MMMC, derivation of control goals
    b. Overview of the options for the control (passively damped, actively damped, decoupled current control, model predictive control, …)
    c. Derivation of the decoupled current control for both topologies
    d. Derivation of the energy control for both topologies
    e. Examples and results

Part 3 (14:00 – 15:30)

5. Operation Modes for Variable-Frequency Operation
   (main focus on: Instantaneous Power Mode [5] and Low Frequency Mode [6] for MMCs; Instantaneous Power Mode [7] and Extended Instantaneous Power Mode [8] for MMMCs)
    a. Principle and motivation of different operation modes for MMCs and MMMCs
    b. Extension of the control system to enable an operation in the different operation modes
    c. Impact of the operation modes on the converter design

Part 4 (16:00 – 17:30)

6. Further Operation Modes and Topology Extensions
    a. Overview of the different options from the literature
    b. Quasi-Two-Level PWM Operation for MMCs
7. Summary and Q&A

Who Should Attend

- PhD students/researchers who are currently starting to work with MMCs
- Experienced researches looking for different approaches to the problems related to the MMCs
- Industry affiliates who are interested in the challenges and an overview of the state-of-art research regarding MMCs for medium-voltage variable-frequency applications

About the Instructors

Axel Mertens graduated from RWTH Aachen, Germany, as Dr.-Ing. in 1992. From 1993 to 2004 he was with Siemens AG, Large Drives division in Erlangen and Nürnberg, Germany, where he was responsible for medium voltage inverters for variable speed drives in the multi-MW range. Since 2004, he is Director of the Institute of Drive Systems and Power Electronics at Leibniz University Hannover, Germany, and Professor for Power Electronics and Drive Control. His research interests include the application of novel devices, condition monitoring and fault-tolerant power electronics, sensorless control of drives, control and stability of grid-forming inverters, and, specifically, Modular Multilevel Converters and their control, including variable-voltage, variable-frequency applications.

Jakub Kucka received the Ing. degree in electrical engineering from Czech Technical University in Prague, Prague, Czech Republic, in 2014. He earned his Ph.D. degree in electrical engineering from the Institute for Drive Systems and Power Electronics, Leibniz University Hannover, Hanover, Germany, in 2019.
Since 2020, he is a postdoctoral researcher at Power Electronics Laboratory, École polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland, where he investigates innovative approaches to realize dc transformers based on resonant converter topologies. His other research interests include modular multilevel converters, their control and design, and control approaches for minimizing the installed module capacitance. He has already authored 17 papers.

Dennis Karwatzki received the Dipl.-Ing. degree in electrical engineering from University of Kaiserslautern, Kaiserslautern, Germany, in 2012, and the Ph.D. degree at the Institute for Drive Systems and Power Electronics, Leibniz University Hannover, Hanover, Germany, in 2017.
Since 2017, he is with Siemens Large Drive Applications, Germany, where he is responsible for the hardware design of modular multilevel converters for medium voltage drives.

References

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