EPE'22 ECCE Europe – Tutorial Announcement

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

Jakub KUCKA
Siemens AG
Large Drives Applications
Erlangen, Germany

jakub.kucka@ieee.org

Rebecca DIERKS
Leibniz University Hannover
Institute for Drive Systems and Power Electronics
Hannover, Germany
rebecca.dierks@ial.uni-hannover.de

Scope and Benefits:

This tutorial focuses on modular multilevel converters (MMCs) and modular multilevel matrix converters (MMMCs) for applications that require a wide range of variable converter output voltages and frequencies. Typical applications with such requirements are medium-voltage drive systems. While the superior voltage quality, the simple voltage scalability, and optional redundancy of both MMCs and MMMCs are attractive, the high complexity of the system is a challenge. It requires special control approaches to enable a stable operation. In this tutorial, the operation principle of these topologies will be explained and control strategies will be presented in detail. An emphasis will be placed on a generalized control approach, proposed by our research group from Hannover, which can be applied to both MMCs and MMMCs, as well as to other similar topologies. Furthermore, specific operation modes will be explained that also cover singular points of the conventional control and thus, allow for a wide range of output frequencies. Besides regular multilevel operation, the quasi-two-level and quasi-three-level operations will be presented, which are capable of reducing the module capacitance by more than one order of magnitude.

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 sizing 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.

Who should attend:

The improved and extended version of the popular tutorial presents the hot research and industry topic in an understandable manner. While being feasible for anybody with a fundamental knowledge in power electronics, the tutorial visits many advanced topics into depth. This makes it ideal for the wide spectrum of audience:

- PhD students/researchers who are currently starting to work with MMCs
- Experienced researchers 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

Schedule:

Friday, 9 September 2022 - 2nd Tutorial Day - Full Day

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
    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. Extended energy control in the event of load or grid faults
    f. 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 with design examples

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
    c. Novel Quasi-Three-Level PWM Operation for modified MMCs
7. Summary and Q&A

References:

[1] M. Hagiwara and H. Akagi, "Control and Experiment of Pulsewidth-Modulated Modular Multilevel Converters," in *IEEE Transactions on Power Electronics*, vol. 24, no. 7, pp. 1737-1746, July 2009.
[2] S. Rohner, S. Bernet, M. Hiller and R. Sommer, "Pulse width modulation scheme for the Modular Multilevel Converter," 2009 13th European Conference on Power Electronics and Applications, Barcelona, 2009, pp. 1-10.
[3] D. Karwatzki and A. Mertens, "Generalized Control Approach for a Class of Modular Multilevel Converter Topologies," in IEEE Transactions on Power Electronics, vol. 33, no. 4, pp. 2888-2900, April 2018.
[4] D. Karwatzki, L. Baruschka, M. Dokus, J. Kucka and A. Mertens, "Branch energy balancing with a generalised control concept for modular multilevel topologies — Using the example of the modular multilevel converter," 2016 18th European Conference on Power Electronics and Applications (EPE'16 ECCE Europe), Karlsruhe, 2016, pp. 1-10.
[5] M. Winkelnkemper, A. Korn and P. Steimer, "A modular direct converter for transformerless rail interties," 2010 IEEE International Symposium on Industrial Electronics, Bari, 2010, pp. 562-567.
[6] A. J. Korn, M. Winkelnkemper and P. Steimer, "Low output frequency operation of the Modular Multi-Level Converter," 2010 IEEE Energy Conversion Congress and Exposition, Atlanta, GA, 2010, pp. 3993-3997.
[7] A. J. Korn, M. Winkelnkemper, P. Steimer and J. W. Kolar, "Direct modular multi-level converter for gearless low-speed drives," Proceedings of the 2011 14th European Conference on Power Electronics and Applications, Birmingham, 2011, pp. 1-7.
[8] W. Kawamura, H. Akagi, "Control of the modular multilevel cascade converter based on triple-star bridge-cells (MMCC-TSBC) for motor drives", Energy Conversion Congress and Exposition (ECCE) 2012 IEEE, pp. 3506-3513, Sept 2012.
[9] J. Kucka, "Quasi-two-level PWM operation for modular multilevel converters: implementation, analysis, and application to medium-voltage drives," doctoral thesis, Leibniz University Hannover, 2019. https://doi.org/10.15488/4827
[10] D. Karwatzki, "Analyse und Regelung einer Klasse von modularen Multilevelumrichter-Topologien," doctoral thesis, Leibniz University Hannover, 2017.

About the Lecturers:

Dr. Jakub KUCKA received the Dr.-Ing. (Ph.D.) degree from Leibniz University Hannover, Germany, in 2019.
From 2014 to 2019, he was a Research Associate with the Institute for Drive Systems and Power Electronics, Leibniz University Hannover, Germany. From 2020 to 2021, he was a Postdoctoral Researcher with the Power Electronics Laboratory, EPFL, Lausanne, Switzerland. Currently, he is with Siemens AG, Germany. He has authored more than 30 scientific publications, one tutorial, and filed five patent applications. His research interests include modular multilevel converters, converter control and design, and resonant converter topologies suitable for high-power dc applications.
Dr. Kucka was the recipient of EPE Outstanding Young Member Award in 2020 and of SEMIKRON Young Engineer Award in 2021.

Rebecca Dierks received the Master of Science Degree from Leibniz University Hannover, Germany, in 2019.
Since 2019, she has been a Research Associate at the Institute of Drive Systems and Power Electronics, Leibniz University Hannover, Germany. Her research focuses on the generalized control approach for a class of modular multilevel converters.