IECON 2008 Tutorial Proposal

Title

The Essence of Matrix Converters

How to easily understand Matrix Converters and their Pros and Cons compared to DC Link AC-AC converter systems

Presenters

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Abstract:

AC-AC converters are being utilized in an increasing number of applications, such as in electric drives where a high power factor mains interface and bi-directional power flow are required. Matrix converters are highly attractive for drives applications and have been around now for three decades, but are still not widely used despite high power conversion efficiency and power density. One possible reason for their under utilization is their perceived complexity since the matrix converter simultaneously performs rectification and inversion and that the modulation cannot be based on a constant DC voltage or current level. Therefore, the main objective of this tutorial is to introduce the participant to matrix converters in a non-mathematical, easy-to-follow style and to provide a basis for a comparative evaluation of the matrix converter concepts against conventional voltage or current DC-link AC/AC converter topologies.

In a first step the basic principle of operation and modulation of voltage and current source converter systems is reviewed. Then the most basic form of an indirect matrix converter (i.e., a voltage DC-link back-to-back converters system with suppressed DC link capacitor) is introduced and discussed concerning output voltage formation, output voltage range, and input current behavior. Subsequently, the circuit topology is extended into an Indirect Matrix Converter (IMC) where the modulation is directly following from the voltage and current source rectifier considerations. Zero current and zero voltage commutation of the IMC are discussed and a simplification of the IMC leads to the Sparse Matrix Converter (SMC) topology. In a next step, the output voltage and input current space vectors available for the direct Matrix Converter (CMC) are compared to those of the IMC, which immediately identifies the equivalence of switching states for both systems. This relationship is then used to translate the IMC modulation into a CMC switching sequence, which also links the knowledge base already established in the literature for both systems.

In order to provide a basis for the system dimensioning, the derivation of a low-complexity analytical expression for the calculation of the IMC and CMC power semiconductors current stresses is presented. Furthermore, the worst-case operating conditions, i.e. providing full torque at standstill or operation with an output frequency close to the mains frequency, are analyzed. In addition, the optimum partitioning of a given silicon area to the power transistors and power diodes is identified for a given operating range in the torque-speed plane.

The third part of the tutorial shows the circuit topologies and a classification of all the matrix converters presented in literature so far, including the hybrid matrix converter, three-level matrix converter and full-bridge matrix converters for supplying machines with an open-end winding.

Finally, the matrix converter topologies are compared with voltage and current DC link AC-AC converter systems concerning the input and output current waveform quality, required input and output

EMI filters to meet EMC requirements, efficiency, compactness, control dynamics, the possibilities for ride-through operation and the semiconductor utilization assuming equal total silicon area employed in the evaluated systems. The theoretical considerations are substantiated by measurement results of experimental systems including an All-SiC current source back-to-back converter and IMC, a RB-IGBT IMC and an Ultra-Sparse Matrix Converter. This clearly reveals the strengths and the weaknesses of the different topologies and leaves the participants with an understanding of the most advantageous application areas of the different systems.

A comprehensive list of references, including the main papers which have been published since the introduction of the Matrix Converter concept in the 1970s, will be provided with the Tutorial handouts.

Presenter(s) Biography

Johann W. Kolar received his Ph.D. degree (summa cum laude) from the University of Technology Vienna, Austria. Since 1984 he has been working as an independent international consultant in close collaboration with the University of Technology Vienna, in the fields of power electronics, industrial electronics and high performance drives. He has proposed numerous novel PWM converter topologies, and modulation and control concepts, e.g., the VIENNA Rectifier and the Three-Phase AC-AC Sparse Matrix Converter. Dr. Kolar has published over 250 scientific papers in international journals and conference proceedings and has filed more than 70 patents. He was appointed Professor and Head of the Power Electronic Systems Laboratory at the Swiss Federal Institute of Technology (ETH) Zurich on Feb. 1, 2001.

The focus of his current research is on AC-AC and AC-DC converter topologies with low effects on the mains, e.g. for power supply of telecommunication systems, More-Electric-Aircraft and distributed power systems in connection with fuel cells. Further main areas of research are the realization of ultra-compact intelligent converter modules employing latest power semiconductor technology (SiC), novel concepts for cooling and EMI filtering, multi-domain/multi-scale modelling and simulation, pulsed power, bearingless motors, and Power MEMS. He received the Best Transactions Paper Award of the IEEE Industrial Electronics Society in 2005. He also received an Erskine Fellowship from the University of Canterbury, New Zealand, in 2003. In 2006, the European Power Supplies Manufacturers Association (EPSMA) awarded the Power Electronics Systems Laboratory of ETH Zurich as the leading academic research institution in Europe.

Dr. Kolar is a Member of the IEEE and a Member of the IEEJ and of Technical Program Committees of numerous international conferences in the field (e.g. Director of the Power Quality Branch of the International Conference on Power Conversion and Intelligent Motion). From 1997 through 2000 he has been serving as an Associate Editor of the IEEE Transactions on Industrial Electronics and since 2001 as an Associate Editor of the IEEE Transactions on Power Electronics. Since 2002 he also is an Associate Editor of the Journal of Power Electronics of the Korean Institute of Power Electronics and a member of the Editorial Advisory Board of the IEEJ Transactions on Electrical and Electronic Engineering.

Simon Round received the B.E. (Hons) and Ph.D. degrees from the University of Canterbury, Christchurch, New Zealand, in 1989 and 1993, respectively. From 1992 to 1995 he held positions of Research Associate in the Department of Electrical Engineering at the University of Minnesota and Research Fellow at the Norwegian Institute of Technology, Trondheim, Norway. From 1995 to 2003 he was a Lecturer/Senior Lecturer in the Department of Electrical and Electronic Engineering at the University of Canterbury where he performed research on power quality compensators, electric vehicle electronics, and cryogenic power electronics. In 2001 he received a University of Canterbury Teaching Award. He has also worked as a power electronic consultant for Vectek Electronics, where he developed a "state-of-the-art" digital controller for high-power inverter systems. In September 2004, he joined the Power Electronic Systems Laboratory at ETH Zurich, Switzerland as a Senior Researcher. His current research interests are in ultra-compact power converters, digital control, medium voltage and high temperature applications of silicon carbide power devices, and the application of sparse matrix converters.
Dr Round has over 75 publications in journals and international conferences. He is a Senior Member of the IEEE and has been actively involved in the IEEE New Zealand South Section, where he was Vice-Chair and Chairman from 2001 to 2004.

Relevant Publications:

1. **Kolar, J. W., Schafmeister, F., Round, S. D., Ertl, H.**, "Novel Three-Phase AC-AC Sparse Matrix Converters," IEEE Transactions on Power Electronics, vol. 22, no. 5, Sept. 2007, pp.1649-1661.
2. **Round, S., Schafmeister, F., Heldwein, M., Pereira, E., Serpa, L., Kolar, J. W.**, "Comparison of Performance and Realization Effort of a Very Sparse Matrix Converter to a Voltage DC Link PWM Inverter with Active Front End," IEEJ Transactions of the Institute of Electrical Engineers of Japan, Volume 126-D, Number 5, May 2006, pp. 578 – 588.

3. **Schafmeister, F., Rytz, C., Kolar, J.W.**, "Analytical Calculation of the Conduction and Switching Losses of the Conventional Matrix Converter and the (Very) Sparse Matrix Converter," Proceedings of the 20th Annual IEEE Applied Power Electronics Conference and Exposition, Austin (Texas), USA, March 6 - 10, Vol. 2, pp. 875 - 881 (2005).
4. **Schafmeister, F., Kolar, J.W.**, "Novel Hybrid Modulation Schemes Extending the Reactive Power Control Range of Conventional and Sparse Matrix Converters Operating at Maximum Output Voltage," Proceedings of the 11th International Power Electronics and Motion Control Conference, Riga, Latvia, Sept. 2 - 4, CD-ROM, ISBN: 9984-32-010-3 (2004).
5. **Schafmeister, F., Kolar, J.W.**, "Novel Modulation Schemes for Matrix- and Sparse Matrix Converters Facilitating Reactive Power Transfer through the Converter System," Proceedings of the 35th IEEE Power Electronics Specialists Conference, Aachen, Germany, June 20 - 25, CD-ROM, ISBN: 07803-8400-8 (2004).

Intended Audience

Researchers and industry people interested in an easy-to-follow introduction to Matrix Converters and a comprehensive understanding of the potential advantages and weaknesses of Matrix Converters against conventional AC-AC converter topologies.

Expected knowledge level in the topic: Basic

Conference Topic Areas: Power Electronics,
Electrical Drives,
Control Systems