Review of the ECPE Workshop on Advanced Multilevel Converter Systems

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With more than 165 participants, the ECPE Workshop held in Västerås (Sweden) has confirmed the growing attention paid to multilevel conversion systems (Figure 1). Initiated by ABB Corporate Research (Dr. Demetriades and Dr. Tenca) the seminar has addressed the many faces of multilevel conversion from topology to control and applications, from very high power to low power.

Figure 1: ECPE Workshop held in Västerås (Sweden)

Topologies

Thirty years after Baker's patent on the Neutral Point Clamped Inverter (NPC), topologies allowing multilevel conversion form a large family and most of these topologies have been presented and compared during the seminar. The most striking topic of the seminar has certainly been the breakthrough of the Modular MultiLevel Converter (M²C) and its variants (Figure 2).

Highly modular with a high number of levels, this topology introduced by Prof. Marquardt (Univ. BW Munich) some ten years ago, seems now clearly recognized as the best topology for HVDC applications. As shown in the presentations by Prof. Clare (Univ. Nottingham), Dr. Gambach (Siemens Energy), Prof. Nee (KTH Stockholm) and Dr. Hasler (ABB Schweden), the major companies in the field (ABB, Alstom and Siemens) have developed slightly different products using this concept and allowing impressive figures such as power up to 200MW and voltages of +/-200kV on the DC bus. The application of the concept in the field of drives is now investigated, but in this field the competition between topologies is more open because the M²C requires roughly twice the amount of semiconductors (sum of Volts.amps of all semiconductors) and 2 to 3 times the amount of energy stored in the capacitors of a 3-level NPC. The problem of stored energy is even more striking when the modulation frequency is low or very low, a situation that definitely needs to be handled in drives. As explained by Dr. Hiller (Siemens Large Drives), some dedicated modulation strategies can reduce the requirement on stored energy, but the more realistic application of M²C in the field of drives is probably on the line side.

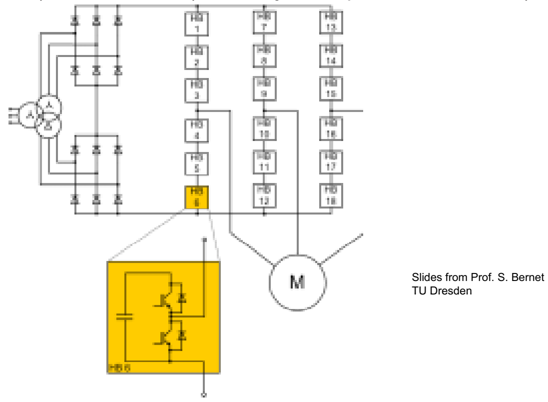

Figure 2: Modular Multi-Level Converter (M2C)

A quite comprehensive review of topologies used in MV drives has been presented by Prof. Bernet (TU Dresden) (Figure 3) showing in particular how the NPC and Flying Capacitor (FC) families gave birth to the newest 5L-ANPC topology. This topology has now been successfully introduced by ABB with 10kVdc in its ACS2000 drive of which details have been presented by Dr. Schlapbach (ABB Switzerland). Today, a clear majority of MV drives now use two back-to-back voltage source inverters multilevel (VSI) converters with semiconductors in series, but we also heard that this is only one part of a bigger picture.

Series multicell VSIs generate multilevel voltage waveforms on the AC side thus improving the harmonic content on the line and on the machine side and this is what makes them so attractive; THD requirements are very high on the line side and on the machine side when long cables are used, and series multicell is a good match for these applications. However, there are cases when the THD and EMC requirements are stronger on the DC side, and onboard networks with a DC bus distributed along the vehicle are such a growing market (Figure 4). Series multicell converters generally do not help in

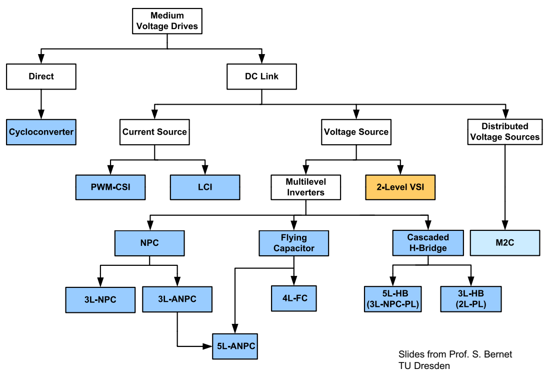

Figure 3: Classification of Converter Topologies on the MVD - Market

these applications because the current on the DC bus is still a 2-level current waveform. It has been shown that switching to parallel multicell gives multilevel current waveforms on the DC side and maintains voltage multilevel waveforms on the AC side, another advantage is that it helps handling the high currents imposed by the demand for increasing powers and with a voltage that is limited for safety reasons.

In the field of very low voltages, this is already used in Voltage Regulator Modules supplying processors with 1V/100A using typically 5 interleaved buck converters and InterCell Transformers to suppress electrolytic capacitors. The concept has been further investigated by Prof. Gateau (Univ. Toulouse) who presented three-phase parallel voltage source inverters and Prof. Laboure (SUPELEC), who derived isolated interleaved converters with reduced filters and a resulting high power density. The potentially high power density of parallel multicell converters has also been confirmed by Prof. Mertens (Univ. Hannover) who showed how the choice of the topology impacts the size of the filters. It has also been shown by Mr. Fritsch (Vincotech) and Mr. Rizet (G2ELab / APC by Schneider Electric) that using parallel multicell conversion and soft switching is a way to reach very high efficiency in low voltage applications (230Vac) which is the key figure of merit in photovoltaic applications and Uninterruptible Power Supplies.

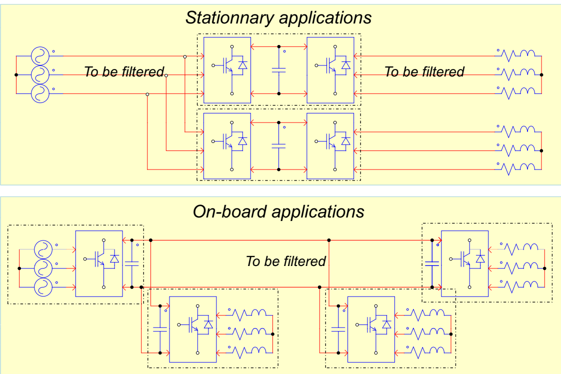

Figure 4: Filtering Requirements for Different Types of Applications

Modulation Strategies

Multilevel converters also offer many degrees of freedom in term of control, and various aspects of the modulation of multilevel converters have been discussed. Dr. Tenca (ABB Sweden) has shown how the practical requirements can be expressed in terms of energy you cannot cheat with, and how some theoretical concepts and methods can help solving some questions related to multilevel converters (modulation strategies, but also safety of operation)! It has also been shown by Mr. Thielemans (Ghent Univ.) how FC converters can be modulated to stabilize the balancing time constant over a wide modulation range, and Mr. Videt (Schneider Toshiba Inverter) described 3-level modulation strategies reducing the Common Mode voltage and the peak voltage generated at the end of long cables. As the number of voltages increases, the need for a generic approach to the control of multilevel three phase VSIs is needed. Such a generic approach using topology independent carrier based strategies and topology specific state machine decoders has been developed in the literature and should be used as a basis for comparison each time a new topology or a new application is investigated. The 5L-ANPC and parallel multilevel converters are no exception to this rule; Dr. Schlapbach applied the method to Direct Torque Control with a five level state machine and Prof. Gateau showed how this generic approach can be applied and adapted to solve some side effects inherent in these configurations.

Optimized and dedicated components

An analysis of existing topologies has been presented by Mr. Schweizer (ETH Zurich) who showed how this analysis can guide the choice of the type of semiconductor, and even its surface to optimize the overall trade-offs. Such an evolution towards optimized components is also noticeable in terms of commercially available modules; Prof. Kaminski (Univ. Bremen) and Mr. Frisch (Vincotech) have outlined the existence of several dedicated multilevel modules, some of them mixing different technologies inside the same module to optimize performance. They also tried to evaluate the potential of wide-bandgap semiconductors in the field of multilevel conversion to push the limits of efficiency and specific mass even further.

Safety issues

Reliability and continuity of operation are critical issues and counting the number of devices does not give all the answer. Various aspects of fault-handling have been discussed by Dr. Pou (TU Catalonia) and Mr. Billmann (Fraunhofer IISB Nuremberg), and it has been shown that if properly handled, faults in multilevel converters can have a limited impact and multilevel converters can be designed with fault tolerance in mind.

Conclusion

Multilevel converters have grown into a mature technology invading many fields of application such as 100MW Flexible AC Transmission Systems, 1-10MW Medium Voltage Drives, 100kW-1MW low voltage Drives and Uninterruptible Power Supplies, 5-50kW PV systems, 1-10kW DC-DC converters for onboard applications and 100-200W Voltage Regulator Modules for processors. The related know-how in terms of modulation, control and design is immense, specific components such as dedicated power modules and specific passive components are available, so now is the time to take advantage of the benefits of multilevel conversion.

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