Electromagnetic Simulations in Power Electronic Converter Design

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Summary The energy efficiency trends in power electronic converter design are leading to increasing demands for faster switching devices with minimal switching losses. Consequences are electromagnetic design challenges such as parasitic stray inductances and high frequency impedance characteristics of passive components. The only way to systematically approach these challenges are dedicated methods for efficient electromagnetic simulation.

1 Introduction

Nowadays, power electronics plays a central role in the discussions on energy efficiency and is therefore gaining high attention in academic and industrial research. With the objective of improving the converter performance in terms of power quality, efficiency and cost, large progress is achieved in power semiconductors research. The consequences are that increasing blocking voltages, current switching capabilities and switching speeds, thus leading to very high d*I*/dt and d*U*/dt, and consequently to an increased complexity of EMI problems to be solved [1]. With the introduction of fast switching wide bandgap semiconductors (i.e. SiC and GaN), this trend will be even more significant [2].

In order to systematically address above EMI problems, dedicated simulation methodologies for power electronic converter design have been developed. Even though the basic power converter circuit topologies are very similar for the various applications, the components used and the electromagnetic effects observed are very different, thus demanding for dedicated numerical methods.

The methods discussed here include 3D field simulations, circuit simulations, semiconductors and passive components macro modeling and model simplification and acceleration methods.

2 Methodologies

One of the most relevant electrical design parameter in a power converter is the stray inductance in the power commutation loops [1]. 3D field simulations magnetic field patterns (Fig. 1), and current density distributions (Fig. 2), are therefore used to characterize and optimize the layouts of power modules [3] bus bars [4, 5] and PCBs for minimal stray inductance.

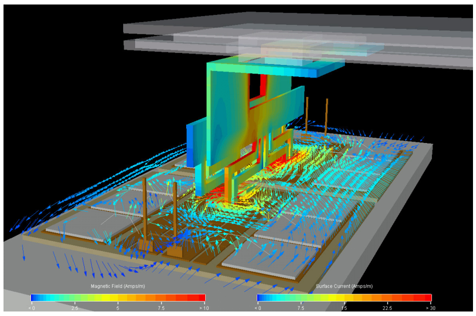

Fig. 1 Magnetic field patterns inside an IGBT power module.

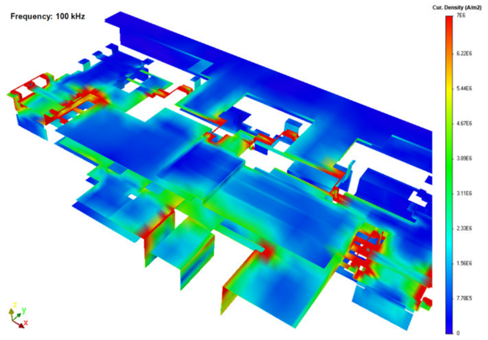

Fig. 2 Current density distribution in planar multi-layer bus bar.

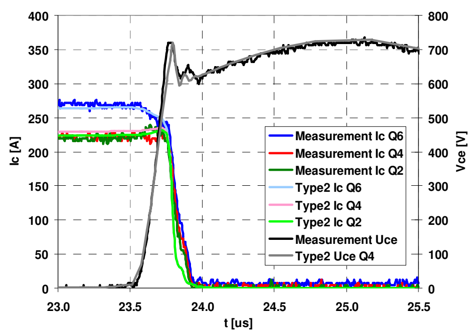

Fig. 3 Comparison of simulated and measured turn-off waveforms.

Extracted bus bar and PCB impedances are then used in circuit simulations to analyze the system switching behavior (Fig. 3) in the time and frequency domain [6, 7]. For that purpose, other system components also need to be modeled and added to the circuit. Most important components are the power semiconductors (IGBTs, diodes) [8] and passive components such as capacitors, chokes (Fig. 4) [9] or cables [10].

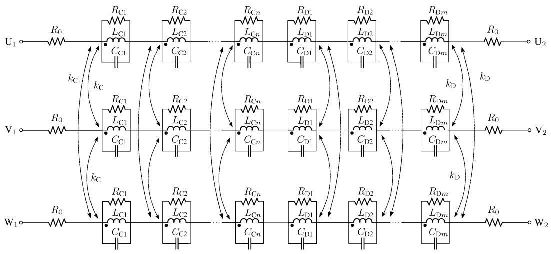

Fig. 4 Equivalent circuit of 3-phase choke.

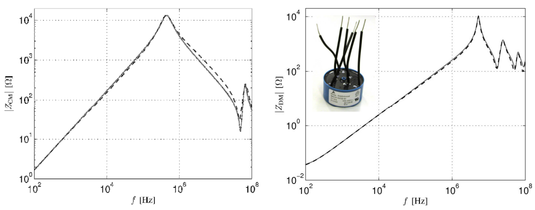

Fig. 5 Comparison of measured and modeled common- and differential mode impedance of a 3-phase choke.

With increasing number and complexity of component models, the computation effort can become prohibitively large and memory demanding. Different acceleration methods have therefore been developed at system model level with divide-and-conquer approaches [7], at component model level with model order reduction [4] and at solver level using reluctance matrix methods [4].

3 Summary

In recent years, electromagnetic simulations have become a powerful tool for power electronic converter design. Major challenges have been to identify the appropriate numerical methods and to develop or adopt efficient simulation platforms and tools for the specific demands of power electronics. Today, the usage of simulations in actual product design is about to become standard, especially for IGBT power modules design, bus bar design and circuit simulation including electromagnetic macro models of active and passive components.

References

1. R. Bayerer, D. Daniel Domes, "Power circuit design for clean switching," In *Proc. 6th International Conference on Integrated Power Electronics Systems (CIPS),* Nuremberg, Germany, 16-18 March, 2010.
2. I. Josifović, J. Popović-Gerber, J.A. Ferreira, "Improving SiC JFET switching behaviour under influence of circuit parasitics", to appear on *IEEE Transactions on Power Electronics*, 2012.
3. D. Cottet, S. Hartmann, U. Schlapbach, "Numerical simulations for electromagnetic power module design," in Proc. *IEEE Int. Sypmosium on Power Semiconductor Devices and ICs, ISPSD 2006*, Naples, Italy, pp 1-4, June 4-8, 2006.
4. D. Cottet, I. Stevanović, B. Wunsch, D. Daroui, J. Ekman, G. Antonini, " EM simulation of planar bus bars in multi-level power converters," to appear in *Proc. IEEE EMC Europe Conference*, Rom, Italy, Sept. 17-21, 2012.
5. D. Cottet, I. Stevanović, "Electromagnetic simulation and design of complex, planar bus bars for multi-level, high power converters," to appear in *Proc. 13th IEEE Control and Modeling for Power Electronics (COMPEL)*, Conference, Kyoto, Japan, June, 10-13, 2012.
6. M. Paakkinen, D. Cottet, "Simulation of the non-idealities in current sharing in parallel IGBT subsystems," in *Proc. IEEE Applied Power Electronics Conference and Exposition*, Austin, TX, USA, Feb. 24-28, 2008, pp. 211–215.
7. I. Stevanović, D. Cottet, B. Wider, D. Daroui, and J. Ekman, "Modeling of large bus bars using PEEC method and circuit level simulators," in *Proc. 12th IEEE Control and Modeling for Power Electronics (COMPEL)*, Conference, Boulder, USA, 28-30 June, 2010, pp.1-7.
8. F. Chimento, N. Mora, M. Bellini, I. Stevanović, S. Tomarchio, "A simplified spice based IGBT model for power electronics modules evaluation," in *Proc. 37th Annual Conference of the IEEE Industrial Electronics Society IECON 2011*, pp. 1096-1101, Melbourne, Australia, Nov. 7-10, 2011.
9. I. Stevanović, S. Skibin, "Behavioral circuit modeling of single- and three-phase chokes with multi-resonances," in *Proc. International Conference on Power Electronics, ECCE Asia*, Jeju, Korea, May 30 – June 3, 2011.
10. I. Stevanović, B. Wunsch, G.-L. Madonna, M.-F. Vancu, S. Skibin, "Multiconductor cable modeling for EMI simulations in power electronics," to appear in *Proc. 38th Annual Conference of the IEEE Industrial Electronics Society*, Montréal, Canada, Oct. 25-28, 2012.