EMC analysis of static converters by the extraction of a complete equivalent circuit via a dedicated PEEC method

Vincent ARDON[1-2], Jérémie AIME[1-3], Edith CLAVEL[1], Olivier CHADEBEC[1], Enrico VIALARDI[2],
Jean-Michel GUICHON[1], Patrice LABIE[1]

[1]Greboble Electrical Engineering Laboratory UJF-CNRS-INPG, BP 46 38402 Grenoble – France
[2]Cedrat, Technological Department-Software, 38246 Meylan – France
[3] Schneider and Toshiba Inverter Europe (STIE), 27120 Pacy sur Eure – France
vincent.ardon@g2elab.grenoble-inp.fr

***Abstract*— This paper presents an application of an adapted (R-L-M-C) PEEC method dedicated to the extraction of equivalent circuit of power electronics devices. Two dedicated integral methods with different meshes are used to compute either resistive and inductive elements or capacitive couplings. The adaptive multi-level fast multipole method (AMLFMM) is presented to extract parasitic capacitances on large geometries. By coupling these two methods, an equivalent circuit with lumped elements is obtained. Consequently, EMC simulations on a wide frequency range are feasible by means of a SPICE-like tool. These methods have been applied to a boost converter.**

I. INTRODUCTION

Nowadays, power electronics systems are getting always smaller and the frequency ranges are rising. A resistive and inductive PEEC model, without parasitic capacitance effects, is rapidly limited to analyze the EM interactions between subsystems or to draw up EMC considerations of the device.

After a brief state of the art of power electronics modeling, two dedicated integral methods and the adaptive multi-level fast multipole method (AMLFMM) are detailed to compute resistances and parasitic inductances and capacitances (sections III and IV). Then, by coupling these two methods, we will see how to build a complete (R-L-M-C) equivalent circuit and evaluate, by means of a SPICE-like tool, the efficiency of whole structures regarding their EMC performances by including power supply chain, commands and loads.

II. STATE OF THE ART

The modeling of power interconnections presents some study constraints: low frequencies (10kHz-200MHz), skin effects, but no propagation effects. Analytical formulations and multi-conductor transmission line theory are limited to model simple geometries with too restrictive assumptions. In fact, they require the exact knowledge of the relative permittivity ε_r and to have a homogeneous media. However, a full (R-L-M-C) PEEC approach would be very memory consuming because different meshes for the inductive and capacitive extractions are needed and both would be very dense. This meshing would be more tailored for very high frequencies (>1GHz).

So, this work proposes a dedicated (R-L-M-C) PEEC method, with two different integral approaches to compute the inductive and capacitive lumped elements. In the next section, a 0-order Galerkin approach is presented to obtain resistive and inductive elements. This is sufficient to model current distributions and near field of power electronics devices with skin and proximity effects [1-2]. In order to improve this model in higher frequencies and to take into account common and differential mode currents, a 0-order point matching method [3-4] and the AMLFMM [5-6] are used to extract parasitic capacitances.

III. COMPUTATION OF (R-L-M) ELEMENTS

This method requires only a meshing of the conductors; air is not meshed (Fig. 1). Between two mesh elements, a mutual inductance is numerically computed. Besides, each element presents a self inductance (analytical formula) and a resistance which is computed with the classical formula R=ρ.l/S. Depending on the directions of the flowing current, conductors can be either unidirectional (thin or long tracks) or bidirectional (large tracks and ground plane). The conductors belonging to the first type are meshed in the skin depth but not in their length, whereas the bidirectional ones are discretized in two directions. These meshes are adapted to model skin and proximity effects. The extracted resistive and inductive dense matrix is efficient to obtain accurate current distributions in the power interconnections of a device [1].

IV. COMPUTATION OF CAPACITANCES

A non-necessarily conformal meshing of the interfaces conductor-dielectric and dielectric-dielectric is used (Fig. 1). Parasitic capacitances between each group of conductor mesh elements are computed from free-charge distributions. A first approach based on a 0-order point matching method can be used [3]. Charge distributions are obtained by solving a linear matrix system with a LU-decomposition. The interaction is composed of potential and normal field coefficients computed between each mesh cell [4]. The worst inconvenient of this method is the storage of the square and dense matrix.

To avoid the slow computation of this dense matrix, the AMLFMM can be used to model large devices. This algorithm accelerates the computation of interaction coefficients and is low-memory consuming by using truncated multipole decomposition of interactions [5-6]. This method subdivides the geometry in cubes of different levels with an adaptive octree algorithm which controls the interaction computations and leads to a compact matrix-vector product. Finally, the problem is solved with a preconditioned GMRES algorithm.

V. APPLICATION TO REAL CONVERTER

These methods are applied to obtain equivalent circuit of a boost converter. Figure 1 shows the two different meshes (inductive and capacitive) used to extract the lumped elements. Figure 2 presents how the complete equivalent circuit is built with the location of capacitances between a conductor and the ground plane, the same implantation could be supposed between two conductors.

VI. POWER ELECTRONICS MODELINGS

A first conducted EMC study of the boost converter is led. With the parasitic capacitances, common and differential loop currents are taken into account in the solving of the equivalent circuit – an InCa3D [2] exported schema-block – in a SPICE-like tool. In fact, the commutations of the boost converter transistor generate common mode currents which flow through parasitic capacitances. Figure 3 shows good agreements between the simulated and measured currents and voltages. Capacitive influences are more visible in high frequencies (>1MHz) as shows the plot of the current's FFT (Fig. 4). It highlights the importance of the taking into accurate account the capacitive effects.

As electrical equations governing the (R-L-M-C) equivalent circuit are implemented in the InCa3D tool, the obtained current distributions inside the conductors can be reintroduced as sources and the near radiated magnetic field can be deduced in post-processing by using the Biot and Savart's law.

VII. CONCLUSIONS

In this paper, it has been presented the coupling between two adapted integral methods allowing, respectively, the extraction of resistive-inductive and capacitive equivalent elements for power electronics interconnections. The interest of such an approach has been analyzed and demonstrated on a real example by comparison with measurements.

It has also been highlighted that the complete (R-L-M-C) equivalent circuit can be exported into a SPICE-like tool where time-domain analysis can be performed. Then, the obtained FFT of the currents inside the conductors has been introduced as sources in the 3D geometric representation of the interconnections for analyzing the EMC performances of the system on a wide frequency range.

REFERENCES

[1] J. Aime, J. Roudet, E. Clavel, O. Aouine, C. Labarre, F. Costa, J. Ecrabey, "Prediction and measurement of the magnetic near field of a static converter", *IEEE International Symposium on Industrial Electronics*, Jun. 2007

[2] InCa3D, Cedrat, www.cedrat.com

[3] O. Chadebec, J.-L. Coulomb, F. Janet, "A review of Magnetostatic Moment Method", *IEEE Transactions on Magnetics*, Compumag, Jun. 2005

[4] V. Ardon, J. Aimé, O. Chadebec, E. Clavel, E. Vialardi, "MoM and PEEC Method to Reach a Complete Equivalent Circuit of a Static Converter", *EMC Zurich*, 12-16 Jan. 2009, Zurich, Switzerland

[5] J. Carrier, L. Greengard, and V. Rokhlin, "A fast adaptive multipole algorithm for particle simulations, *SIAM J. Sci. Statist. Comput. 9*, 669 (1988)

[6] A. Buchau, W. M. Rucker, "Capacitance computation of thin conductors with the fast multipole method", *International Journal of Applied Electromagnetics and Mechanics*, vol.17, 75–89, 2003

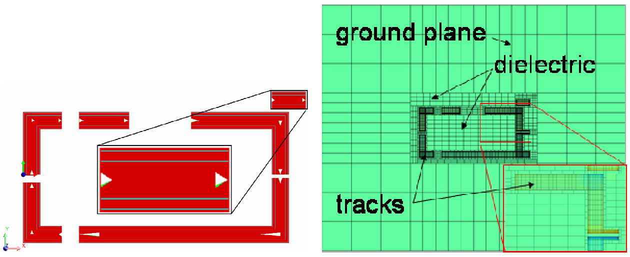

Figure 1: Inductive (on the left) and capacitive (on the right) meshes of the boost converter

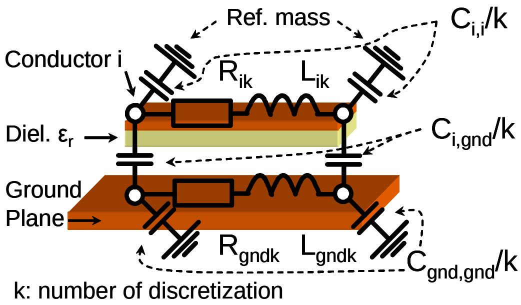

Figure 2: Parasitic capacitance location

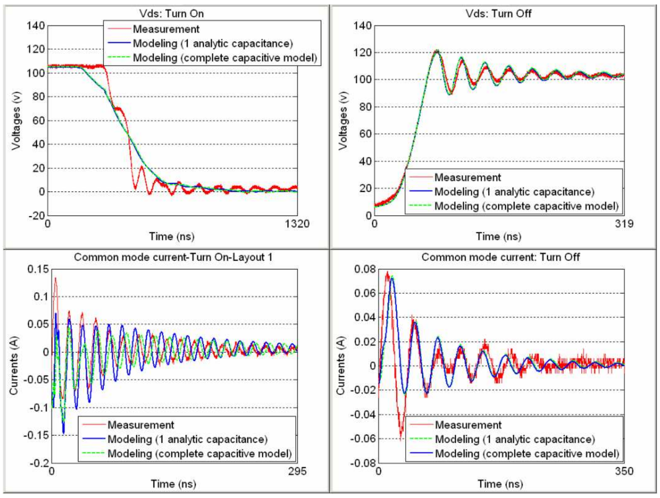

Figure 3: Drain-Source voltage (top panels) and common mode current (bottom panels) of the boost converter during turn-on (on the left) and turn-off (on the right) commutations

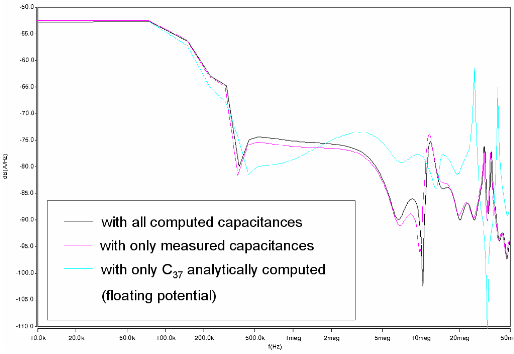

Figure 4: FFT of the common mode current (turn-off)