Model Order Reduction Using COMSOL Multiphysics® Software - a Compact Model of a Wireless Power Transfer System

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Abstract

This work presents the application of mathematical methods of model order reduction (MOR) for automatic generation of highly accurate, compact models for wireless power transfer systems. We apply a block two-sided second order Arnoldi algorithm to automatically compute a compact model, which is highly accurate, but only demands several orders of magnitude smaller CPU time and can be used for the co-simulation with electrical circuitry.

Wireless power transfer (WPT) systems facilitate the use of battery powered devices ranging from handheld devices to electrically powered vehicles. Electrical plugs are made redundant as electrical energy is transmitted without the need of a wired electrical connection. Such systems feature two electrical windings and supporting magnetic components. Energy is transferred to the mobile component by means of magnetic resonance coupling. We focus our work on analyzing the power transfer efficiency, which is strongly affected by the vertical and horizontal alignment of the winding discs, which can be studied within a reduced order model.

For compact modeling, we build a 3D model using the AC/DC Module of COMSOL Multiphysics® software following the specification in [1]. Its geometric setup is presented in Figure 1(left). Figure 1(right) shows the model's mutual inductance behavior in dependence of vertical and horizontal displacements of both windings. The design goal is to maximize the mutual inductance while simultaneously avoiding its sensitivity to the displacement of the windings.

Spatial discretization of Maxwell equations by finite element method (FEM) leads to a frequency domain model (see Figure 2) with 110.000 degrees of freedom (DOFs). The excessive computational effort for the solution of full-scale model prohibits its integration in a co-simulation with electric circuitry. A compact, numerically more efficient model is needed. A lumped representation, composed of a network of resistors, capacitors and inductors, is commonly used as a compact modeling approach [2]. However, such a model is less accurate, only valid for a certain operational regime and cannot be made automatically. Mathematical model order reduction (MOR) has been proven as a reliable modelling approach [3], which is formal, numerically robust and can be fully automated.

By using LiveLink™ for MATLAB® we extract the spatially discretized frequency-domain model and combine the SOAR algorithm as presented in [4] with the two-sided block Arnoldi from [5] to compute a compact model with only 20 DOFs. This reduces the solution time for a harmonic solution for several orders of magnitude, with a negligible loss of accuracy (see Figure 3).

By taking advantage of the IEEE standard format VHDL (Very High Speed Integrated Circuit Hardware Description Language), the reduced model of the electromagnetic system was exported as an electrical two port device. This made it possible to couple the numerical device model to an electrical circuit for the evaluation of power transfer efficiency (see Figure 4) and further design optimization.

Reference

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[4] Z. Bai and Y. Su, SOAR: A second-order Arnoldi method for the solution of the quadratic eigenvalue problem, SIAM J. on Matrix Analysis and Applications, 26(3), pp. 640-659 (2005)

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Figures used in the abstract

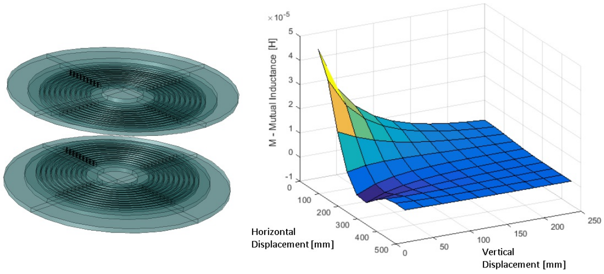

Figure 1: (left) 3D model of coil arrangement, (right) Mutual inductance versus horizontal and vertical coil displacement.

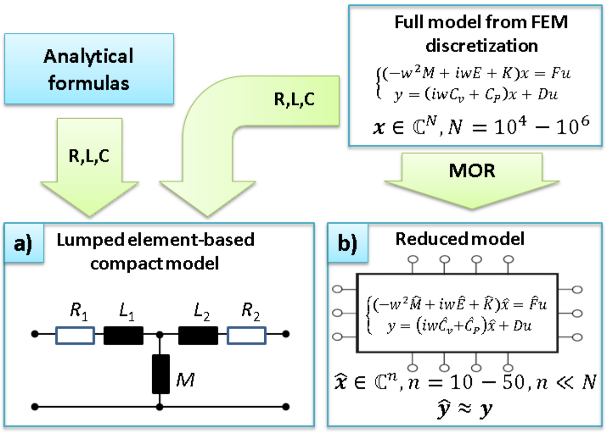

Figure 2: Compact transformer models: a) Lumped element-based b) As derived from finite element model via MOR.

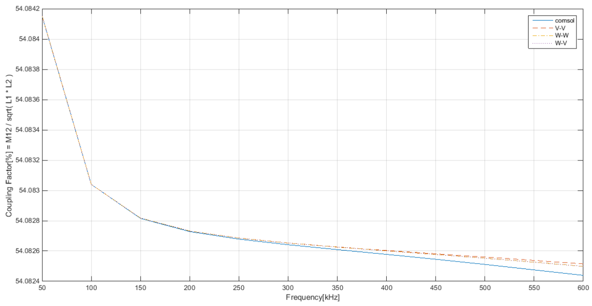

Figure 3: Coupling factor versus vertical coil displacement. Results obtained by model order reduction (DOF = 20) match exactly with the full model (DOF = 110.000).

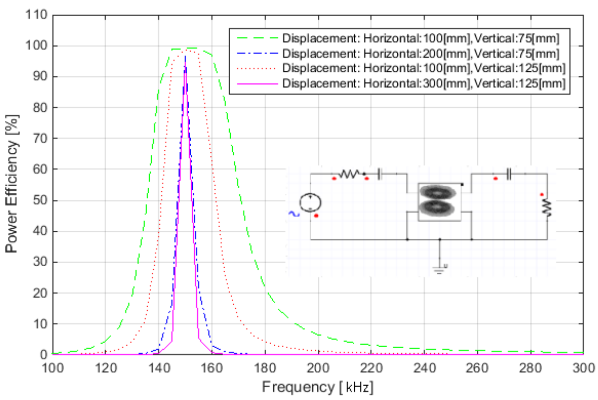

Figure 4: Power transfer efficiency for different vertical and horizontal displacements.