Comparing Partial Element Equivalent Circuit and Finite Element Methods for the Resonant Wireless Power Transfer 3D Modeling

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***Abstract*—In this paper, the unstructured Partial Element Equivalent Circuit (PEEC) method is applied in 3D magnetodynamics to resonant Wireless Power Transfer (WPT) coils modeling. A particular attention is paid on the coupling with circuit equations in order to model the resonant conditions at the circuit and field levels. A preliminary comparison with 3D finite element method highlights the high potential of the PEEC method for the modeling of WPT coils.**

***Index Terms*—Finite Element, Inductive Power Transfer, Integral Method**

I. CONTEXT AND OBJECTIVES

Power electronics current state of the art allows the generation of high power at a frequency level paving the way to the implementation of resonant Wireless Power Transfer (WPT) for energy-greedy applications (*e.g.* electric vehicles battery charging). The computational electromagnetic modeling of coils used for WPT is crucial. On the one hand, it allows to overtake the restricted validity domain of analytical approaches. On the other hand, it permits to compute the space distribution of magnetic quantities, and consequently assess the influence of the WPT device on its environment. Applying the Finite Element (FE) method, considered as a reference method in electrical power engineering, to WPT is not a trivial task. Indeed, the lack of magnetic core induces a significant magnetic flux dispersion, so that a large portion of air around the coils needs to be meshed. Moreover, the skin and proximity effects imply a fine mesh in and around the conductors, leading to a high computational burden. The Partial Element Equivalent Circuit (PEEC) method is an integral method which requires the mesh of active materials only [1]. Moreover, a strong coupling with circuit equations is mandatory since WPT systems are based on resonant RLC circuit to achieve a high efficiency. By doing so, the resonant conditions can be simulated at the circuit and field levels. Even if such a coupling is possible with the FE method, the natural circuit interpretation of the PEEC formulation is more direct. In this digest, 3D PEEC and FE methods in magnetodynamics with strong circuit coupling are compared for an example for which exact analytical approaches exist in order to evaluate the accuracy of both methods.

II. FORMULATIONS

A FE 3D magnetodynamic $\mathbf{a}$-v formulation, with $\mathbf{a}$ the vector magnetic potential and v the scalar electric potential, with strong circuit coupling, is employed. Conductors are modeled as massive, allowing the inclusion of skin and proximity effects appearing at the WPT working frequency level. The unstructured (or generalized) PEEC formulation is based on the development of the Faraday's law where $\mathbf{a}$ and v are expressed as integral forms involving the current density $\mathbf{j}$ in the active conductors. The unknown $\mathbf{j}$ is approximated thanks to facet elements, allowing the use of general unstructured meshes, as with the FE method.

III. PRELIMINARY RESULTS

The PEEC high potential is demonstrated by considering two single loops (of 5 cm radius and spaced by 2 cm) in DC conditions to extract their mutual inductance M using circuit relations. The relative error committed using PEEC and FE methods is evaluated with respect to the analytical value of M. A PEEC simulation is done and several FE simulations are executed in order to achieve the same accuracy than using the PEEC method by refining the mesh in the surrounding air. A huge cylindrical box of air of 75 cm radius and 1.25 m height is mandatory to achieve the targeted accuracy with FE. The results and associated computational performances (on 2.6 GHz i7-6700HQ with 16 Gb RAM) are gathered in Table I.

Method	# of elements	CPU time (s)	Relative error
PEEC	1 536	178	0.57 %
FE	54 165	14	1.50 %
	100 981	52	1.07 %
	266 001	382	0.78 %
	585 971	1970	0.57 %

TABLE I: Comparison of PEEC and FE methods

One can observe the computational gain afforded by the PEEC method. Moreover, at higher frequency, this gain is expected to be even more important since the associated mesh refinement in the conductors will drastically increase the number of elements in the surrounding air. Besides, the mesh control is widely eased using the PEEC method (saving preprocessing time). In the full paper, the aim is to improve and optimize the coils modeling while increasing the frequency (up to tens of kHz) and to simulate a full system (including its source, resonant capacitors and load) in its resonant state.

REFERENCES

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