

# Computational Strategies Improvement for the Generalized PEEC Method

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**Abstract**— Computational strategies improvement for general unstructured-PEEC (Partial Element Equivalent Circuit) method in frequency and for the modelling of low frequencies electromagnetic problems are presented. A general circuit representation is proposed allowing the treatment of multiply connected regions and the coupling with external circuits and coil keeping good computation performances.

**Index Terms**— Quasi-static, Integral method, generalized PEEC method.

## I. INTRODUCTION

In this paper, we present a general magneto-harmonic integral formulation, limited to low frequencies, for the resolution of eddy current problems in the context of industrial power electronics devices modelling. The principle of the PEEC method is to express the electric field  $\mathbf{E}$  in its integral form using Green's function over conductive media and to match it with the constitutive law  $\mathbf{E}(\mathbf{J})$ . The use of 2-form Whitney face interpolation for current density  $\mathbf{J}$  leads to the unstructured PEEC method as proposed in [1]- [3]. The formulation enables the modeling of electromagnetic devices efficiently through circuit representation and the natural conservation of the current across the faces of the mesh.

The formulation which is limited in this paper to linear conductive media has the ability to couple several regions of different types (line 1D, surface 2D [2], and volume 3D) with circuit-like components which can be passive (resistances, inductances, capacitors) and active (current sources, voltage sources). Multiply connected regions problems mixing all these kinds of electric regions and components can be addressed. The approach being general, magnetic and dielectric medias can also be treated like proposed in [1], [3].

## II. DEDICATED INTEGRATION STRATEGY FOR PEEC

A key point of the method is the computation strategy of the integral associated to the Green's kernel for both near and far field interactions which can suffer from inaccuracies and can be very time consuming. This is why today, the use of the PEEC method is often limited to solving academic problems.

A major drawback which limits the use of integral methods is the computation of dense matrices that are generated. Fortunately, it has been overcome thanks to the efficient Adaptive Multi Level Fast Multipole Method (AMLFMM) matrix compression algorithm for the computation of far field interactions, which allowed a significant gain in memory and in computing time. Additionally to AMLFMM, we focus in this work on the improvement of the near field interactions computation. Concerning the accuracy, we have developed an adaptive Gauss points procedure for the Green's kernel integration. We

handle it using semi-analytic integration for very near part (which may have singularities), and full numerical integration for the other part. A parallelized computation procedure which will be explained in the full paper has been developed.

Additionally to the classical treatment of 3D volume regions, we have also included line regions and surface thin regions in order to reduce the number of degrees of freedom. Geometric segments are used to describe 1D region but the integration is made on a volume (hexahedron) which surrounds the line. With such a strategy, the proper partial inductance of each line element is accurately computed. For thin (i.e. surface) regions, an equivalent complex conductivity  $\mathbf{E}(\mathbf{J})$  constitutive law is used to take into account the non-uniform current distribution across the thickness like proposed in [2].

In order to speed-up the iterative resolution process, a preconditioning technique has also been used lying on a LU decomposition of the resistive matrix and the proper inductances of each element.

## III. NUMERICAL EXAMPLE

Several validations have been made, considering line 1D, thin 2D or volume 3D regions models and using the integration strategies presented above. The figure 1 presents a problem with an industrial complexity. It is a laminated busbar of a three-phase inverter, with circuit-type components (resistances, capacitors and a voltage source) connected to the material through connection surfaces. The computing performance obtained is very good if we consider that the problem is composed of a very dense mesh. We used a computer with Intel® Core™ i7-7820HQ CPU @2.90GHz. 2.90GHz processor with 64 Go of RAM.

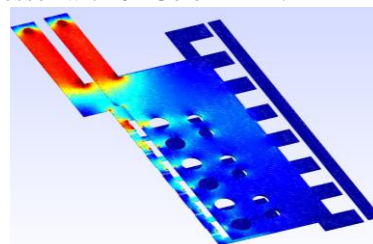


Fig. 1. Current density in a laminated busbar of a three-phase inverter (122,000 tetrahedrons mesh elements, Time of resolution: 25 mn).

## REFERENCES

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