Electromagnetic model in finite volumes for magnetohydrodynamic breaking application

Loïc Rondot, Vincent Mazauric, Yves Delannoy, Gérard Meunier

Electromagnetic Model in Finite Volume for Magnetohydrodynamic Breaking Applications

Loïc Rondot[1,2], Vincent Mazauric[1], Yves Delannoy[2], Gerard Meunier[3]

[1]Schneider Electric Corporate Research and Development, 38050 Grenoble cedex 9, France
[2]MADYLAM-EPM INPG/UJF-CNRS UPR 9033 EPM/ENSHMG – BP 95 38402 Grenoble, France
[3]Laboratoire d'Electrotechnique de Grenoble INPG/UJF-CNRS UMR 5529 LEG/ENSIEG – BP 46, 38402 Grenoble, France

***Abstract* — A magnetodynamic formulation is developed using the finite volume method to address specific issues in plasma physics related to current breaking applications. The conservation of the electrical power is shown to be an efficient and original method to solve the Faraday's law of induction which contrasts with other available solutions.**

I. Introduction

Plasma modeling requires thermohydraulic and electromagnetic models. Whereas conventional Finite Volume (FV) Computational Fluid Dynamics codes enforce local conservation of mass, momentum and energy [1]; low-frequency electromagnetic software minimizes a global energy functional within the finite elements method (FEM). Hence, magnetohydrodynamics problems are currently resolved by using:

- either a FE-CFD code, which involves time-consuming calculations as soon as non-linearity occurs;
- or an hybrid method combining a FV and a FE, thereby sacrificing the high level of integration and the accuracy achieved with a single mesh [2].

Thus, the search for a common, effective and integrated model calls for a single numerical method for the two phenomena. In this work, we opted for an electromagnetic model based on the FV method.

The FV method is based on local conservation, *i.e.* the dissipative term matches the variation over time in any elementary volume and the flux exchanged at it boundary. For example, the local power balance is represented by:

$$\underbrace{\mathbf{H}\cdot\partial_t\mathbf{B}}_{\text{unsteady term}} + \underbrace{\mathrm{div}\,\mathbf{R}}_{\substack{\text{flux}\\ \text{term}}} = \underbrace{-\mathbf{J}\cdot\mathbf{E}}_{\substack{\text{dissipative}\\ \text{term}}} \qquad (1)$$

Thanks to the Poynting's theorem, the conservation of the electromagnetic power density enforces the Faraday's law provided that the Maxwell-Ampere equation is checked [3]. Hence, the continuity laws to consider to solve a magnetodynamic problem are as follow:

- the conservation of the current density;
- the conservation of the magnetic flux density;
- the conservation of the power density.

II. Modeling

The case shown at figure 1 represents a metal slab excited by a time-harmonic magnetic field **H**. The aim is to validate with the CFD *Fluent®* code, the calculation of the induced field in the slab only using a 1D model of a material with a uniform magnetic permeability. The solution of the Maxwell-Faraday equation is derived from the local conservation of power density (1).

Fig. 1. Diagram of the slab along with the applied magnetic field and its FV mesh where the conservation laws are expressed.

III. Results

As expected in the classical skin depth effect, the excitation oscillating around the slab yields an evanescent field in the conductor (figure 2). The agreement with 1D analytical solution is lower than 0.7% mainly located in the skin depth.

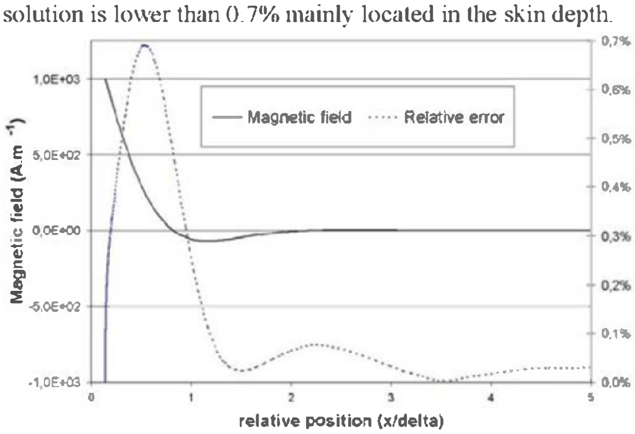

Fig. 2. Induction in a metal slab (continuous) and error introduced by an FV calculation in comparison to the analytical solution (dashed).

IV. Conclusion

Faraday's law of induction may be derived from the power density conservation. Its implementation within a 3D finite volume electromagnetic software is under progress and will allow:

- to model within a strong coupling both fluid and electrical aspects of the plasma physics,
- to consider parallel computation of the conservation equations on the finite volumes.

Subsequent improvements and productivity in the design of breaking products (MV and LV circuit-breaker) are expected.

V. References

[1] P. Chévrier, M. Barrault, and C. Fiévet, "Hydrodynamic model for electrical arc modeling," *IEEE Transactions on Power Delivery*, vol. 11, pp. 1824-1829, 1996.

[2] Ian J. Lyttle "Use of MPCCI to Perform Multidisciplinary Analyses for Electrical Distribution Equipment", *American Institute of Aeronautics and Astronautics*, paper 0122, 2005.

[3] V. Mazauric, "From thermostatistics to Maxwell's equations: A variational approach of electromagnetism," *IEEE Transactions on Magnetics*, vol. 40, pp. 945-948, 2004.