Sensitivity Analysis of Geometrical and Material Uncertainties on RL Parameters of Wound Inductors

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In this work, we analyze the sensitivity of the RL parameters of wound inductors extracted using the Finite Element (FE) method with respect to geometric and material uncertainties, from low to medium frequencies (DC to 1 MHz). To that end, we compute the Sobol indices associated to a Polynomial Chaos Expansion (PCE) of the uncertain FE model.

Numerical models of a physical system almost always depend on uncertain parameters. For instance, wound inductors are characterized by material (i.e. material properties which are not known precisely) and geometric (i.e. conductors positions in the winding window) uncertainties. A correct modelling of such uncertainties, as well as a good understanding of the sensitivity of physical quantities w.r.t uncertainties, is fundamental for ensuring an optimal design of the component. The Finite Element (FE) method can be employed to capture these uncertainties in RLC models using a Monte Carlo simulation approach. However, performing a sensitivity analysis with such a model is very CPU intensive. In this work, we develop a stochastic surrogate model of wound inductors based on chaos polynomial expansion (PCE), in order to mitigate this problem. We then compute the Sobol indices over a wide range of frequencies (DC to 1MHz) in order to quantify the sensitivity of the PCE surrogate

The overall methodology is built upon a 2D magnetodynamic FE model for extracting RL parameters, in combination with an original algorithm mimicking the manual wounding operation for specifying the uncertain positions of conductors in the winding window. It is depicted in Figure 1. We compute a PCE surrogate in order to reduce the number of numerical model calls needed to perform a Monte Carlo simulation (with a brut FE model). In addition to this, we compute the Sobol indices from the PCE surrogate, which does not require any additional evaluation of the deterministic model. The uncertainties taken into account in this study arise from random positions of conductors in the winding window and from material properties of ferrite core (magnetic permeability $\underline{\mu}_{core}$ and electrical conductivity σ_{core}). The complex form of material properties allows to take into account in a natural way the electrical and magnetic losses in finite elements formulations. The reduction in the dimension of the random input is achieved through the transformation of geometrical uncertainties (positions of conductors) into material ones (equivalent magnetic reluctivity $\underline{\nu}_{prox}$ related to the proximity effect and equivalent impedance $\underline{Z}_{skin}$ related to the skin effect) via homogenization technique.

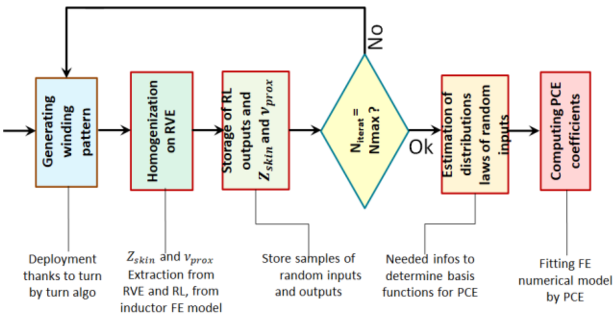

Figure 1: Process of PCE surrogate construction.