

Homogenization of windings in harmonic-balance finite-element modelling of electromagnetic devices

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Accounting for the sometimes non-negligible skin and proximity effects in the windings and electromagnetic devices requires a brute-force finite-element model with a fine discretization of the winding, which is most often computationally prohibitive in terms of memory and time.

Ad-hoc frequency-domain homogenization methods consist in adopting complex reluctivity and resistance values in the homogenized winding region and electrical circuit, respectively. A general identification approach along with a time-domain extension is proposed in (J. Gyselinck, R.V. Sabariego and P. Dular, "Time-domain homogenization of windings in 2-D finite element models," *IEEE Trans. on Magn.*, vol. 43, no. 4, pp. 1297-1300, 2007).

The harmonic-balance (HB) or multi-harmonic approach allows obtaining the periodic steady-state solution through the resolution of a single, but larger, system of algebraic equations, after having truncated the frequency spectrum of the magnetic field. One can thus compromise between accuracy and computational cost, compared to the straightforward time-stepping approach (with the inevitable transient to traverse). The Galerkin time-domain approach to HBFEM modelling presented in (J. Gyselinck, P. Dular, C. Geuzaine, W. Legros, "Harmonic-balance finite-element modeling of electromagnetic devices: A novel approach," *IEEE Trans. on Magn.*, vol. 38, no. 2, pp. 521-524, 2002.) allows to straightforwardly include the various sources of harmonics (other than the ones present in the source terms), namely magnetic saturation, nonlinear lumped components in the circuits (e.g. diodes) and movement or rotation.

In this paper, we propose to combine the approaches of the two above cited papers and develop two significant examples by way of illustration and validation. A saturable inductor with multi-turn coil will be considered, together with either sinusoidal or pulse-width modulated (PWM) voltage supply. For each of the considered frequencies in the HB approach, a different complex reluctivity and resistance value is adopted. Four different approaches can be thus compared: without or with homogenization of the winding, and with plain time stepping or with the HB approach, for focusing on both local and global results.