Three-dimensional modeling of multilayer busbar incorporating domains of lesser dimension

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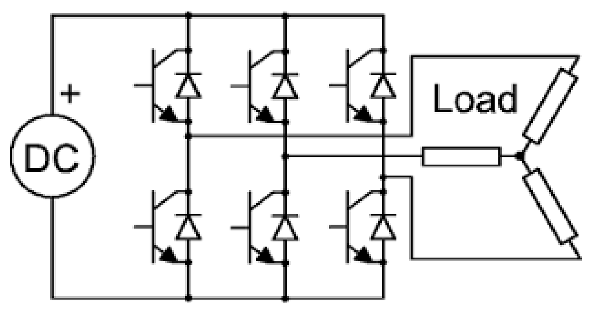
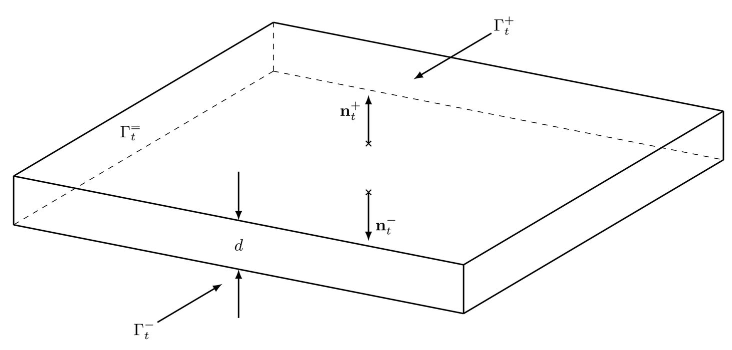
Introduction

For the accurate modeling of a busbar, it is needed to solve the full-wave Maxwell's equations, to include inductive and capacitive effects, in the calculation of the input impedance. Their operation at higher frequencies is costly as the skin depth becomes smaller than the thickness of the conducting domain. The challenge therein lies in finding a trade-off between computational cost and the accuracy of the solution.



Thin Shell Model

Let us consider a wide structure with infinitesimal thicknes d. Under these conditions we may assume that the current distribution across the thin structure will occur tangentially to the larger surface, and negligible across the thickness.



Performing the analytic integration of the 1D problem we may express the volume integral of the $\boldsymbol{curl h}$ as

$$\int_V \boldsymbol{curl h}\, dV = \sigma \frac{tanh(\gamma \boldsymbol{d}/2)}{\gamma} (\boldsymbol{e}_t|_{\Gamma^+} + \boldsymbol{e}_t|_{\Gamma^-})$$

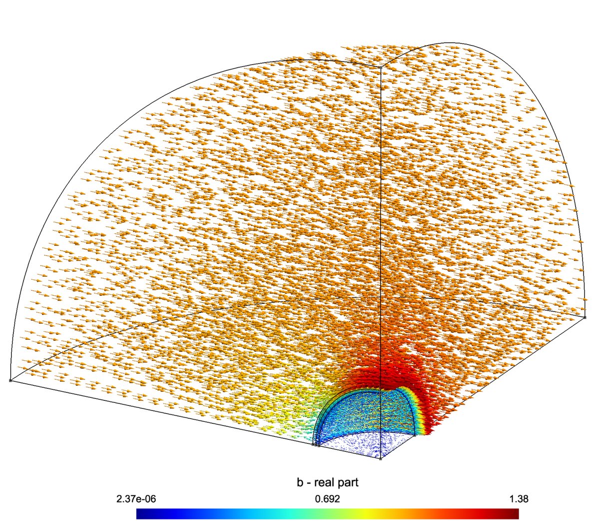
Where $\gamma = \sqrt{i\omega\sigma\mu(1+\frac{i\omega\epsilon}{\sigma})}$

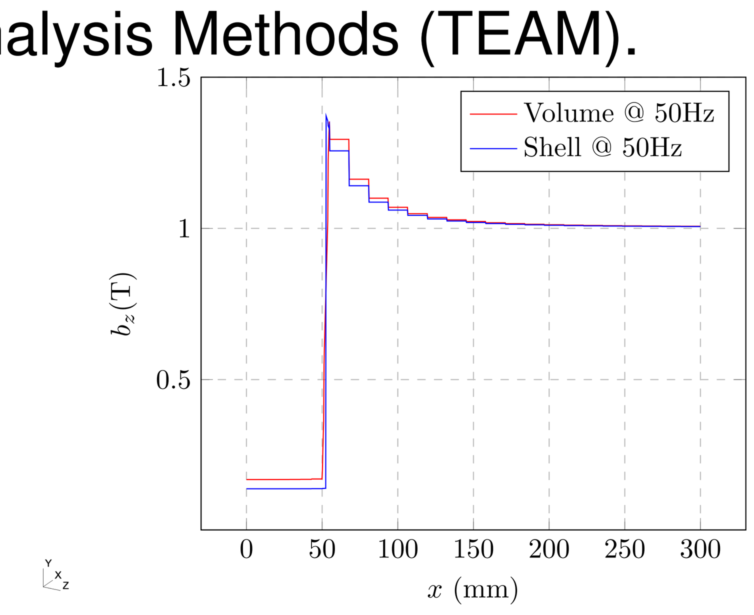
The physical model can be coupled to a finite element model where it can be used as a type of impedance boundary condition, tied to the traces of the magnetic field and the relationship to the magnetic vector potential.

$$\hat{\boldsymbol{n}}_t \times \boldsymbol{h}_t|_{\Gamma^+} + \hat{\boldsymbol{n}}_t \times \boldsymbol{h}_t|_{\Gamma^-} = -\frac{1}{\mu\beta_0}\boldsymbol{a}_{c,t}|_{\Gamma^+}$$

$$\hat{\boldsymbol{n}}_t \times \boldsymbol{h}_t|_{\Gamma^+} - \hat{\boldsymbol{n}}_t \times \boldsymbol{h}_t|_{\Gamma^-} = -\sigma\beta_0 i\omega(2\boldsymbol{a}_{c,t}|_{\Gamma^+} + 2\boldsymbol{a}_{d,t}|_{\Gamma^+})$$

The results at low frequency can be compared to Problem 6 of the Testing Electromagnetic Analysis Methods (TEAM).



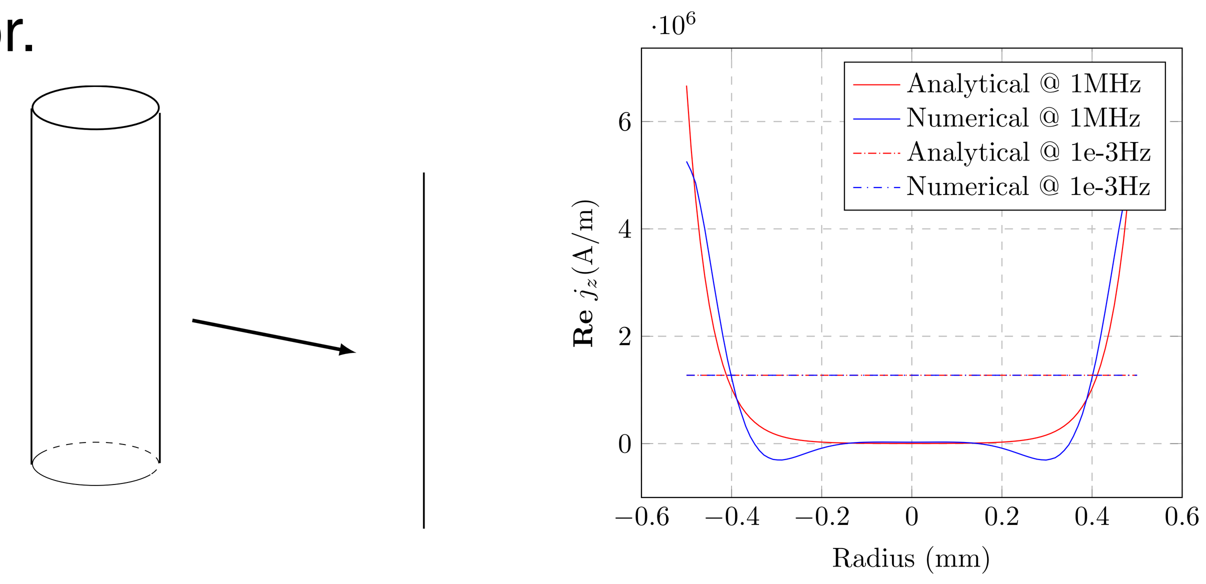


Line Region and Bessel Functions

The behavior of the current density in the time-harmonic case can be described in terms of modified Bessel functions.

$$\boldsymbol{j} = \textbf{Re}\left[\frac{i^{3/2}\boldsymbol{k}J_0(i^{3/2}\boldsymbol{k}\, r)}{2\pi \boldsymbol{R}\, J_1(i^{3/2}\boldsymbol{k}R)} I\ exp^{i(\omega t-\beta z)}\right]\hat{z}$$

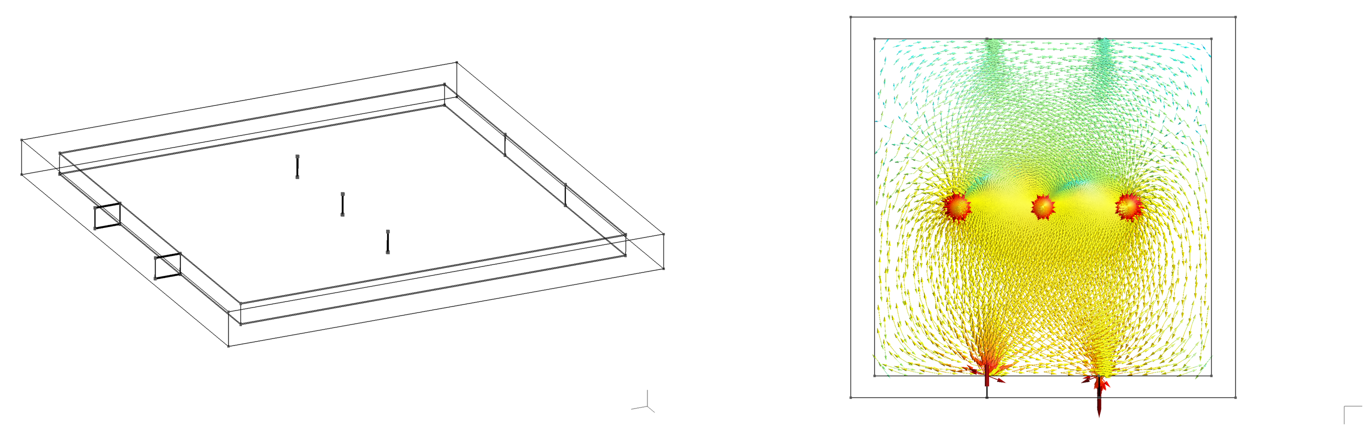
The assumption is that in an infinitesimal long wire, the current density distribution will be symmetrical to the central axis of the conductor.



$$\int_A \hat{\mathbf{n}} \cdot \boldsymbol{j} dA = -\sigma i\omega \boldsymbol{a}_s \textbf{Re}\left[\frac{2\pi \boldsymbol{R}\, J_1(i^{3/2}\boldsymbol{k}R)}{i^{3/2}\boldsymbol{k}J_0(i^{3/2}\boldsymbol{k}R)}\frac{1}{exp^{i(\omega t-\beta z)}}\right]$$

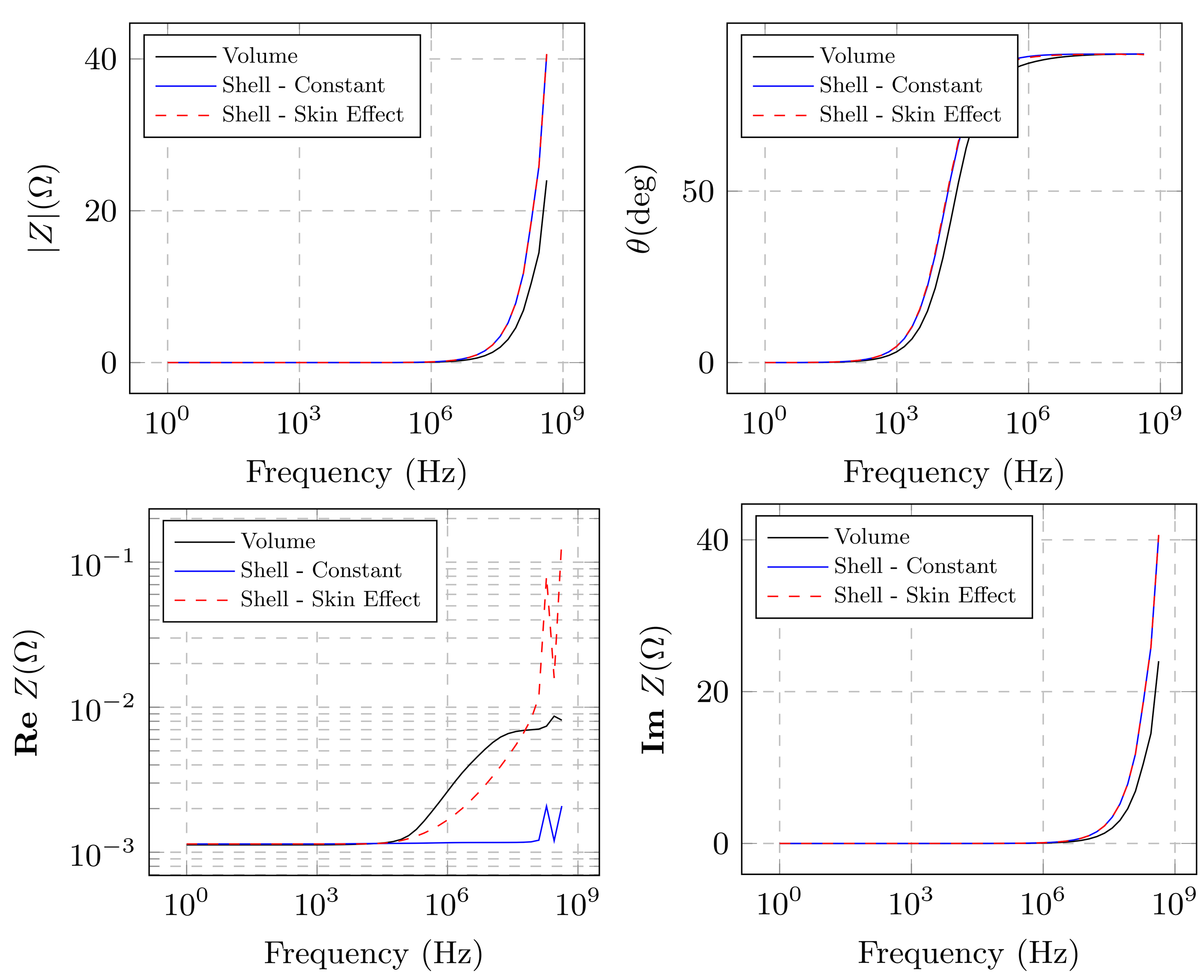
Busbar Model and Input Impedance

Busbars are commonly used for power distribution in a variety of applications including circuit coupling and load control. Due to the diversity in functionality, their size and shape vary substantially from design to design, although their main concept resembles that of a parallel-plate transmission line, consisting of parallel conducting plates separated by a dielectric slab.



This model aims to replicate the behavior of a no-load three-phase inverter, where we have an input terminal and three vias representing the IGBTs of the inverter.

The results below show the behavior of the impedance at a wide range of frequencies. Although the phase shows that the busbar is mainly inductive, it is possible to see the effect of the skin effect on the real part of the impedance



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