

Massively Parallel Hybrid TLM-PEEC Solver and Model Order Reduction for 3D Nonlinear Electromagnetic Transient Analysis

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Electromagnetic (EM) equipment are ubiquitous in electrical power generation, transmission, and distribution systems, and they should be studied for reliable and continuous operation under switching operations, faults, and other transient conditions. Conventional lumped models lack the capability to consider EM field interactions, while distributed methods, such as the finite element method (FEM), are widely employed to address these interactions. The partial element equivalent circuit (PEEC) method has gained interest in EM modeling due to its equivalent circuit behavior and its potential for optimization using circuit solver techniques. This article extends the hybrid transmission line modeling (TLM) based PEEC 2-D solver for 3-D EM transient simulations, providing detailed information on the matrix solver, time-domain algorithm, the parallelized the Newton–Raphson (N–R) solver for nonlinear magnetics, and a suitable model order reduction (MOR) method. The hybrid TLM–PEEC technique decouples the nonlinear elements from the linear network, providing individual solutions for each unknown through N–R iterations, thereby enabling parallel computing. The proper orthogonal decomposition method, a MOR technique, was integrated into the hybrid TLM–PEEC method to improve performance by removing unnecessary features in the system. The parallelization of the methods has been fully explored and implemented on both many-core graphics processing unit and multicore central processing unit, enabling field-oriented transient simulation for a 3-phase 3-D core-type transformer coupled with external circuits, as well as quasi-static 3-D simulation for a high-voltageinsulator. The accuracy and computational efficiency of the proposed were verified through simulation results obtained from similar case studies implemented in Comsol Multiphysics.