Information-Based Model Reduction for Nonlinear Electro-Quasistatic Field Problems

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Abstract

We suggest a model reduction framework for transient nonlinear electro-quasistatic (EQS) field simulations of high-voltage devices that comprise strongly nonlinear electric field stress grading material. High-fidelity snapshots are obtained with the finite element method (FEM) along with implicit time quadrature (BDF1). The singular value decomposition (SVD) is employed to obtain the proper orthogonal decomposition (POD) modes [1], whilst nodes at which interpolation constraints are imposed, are selected according to absolute and relative information criteria.

Since strongly nonlinear behavior is essentially irreducible, the developed so-called maximal information refinement (MIR) strategy incorporates the indices of high-information content nodes into the interpolation index set. More precisely, at each node of the computational domain, we assign the spectral Shannon entropy [2] and the spectral Kullback-Leibler divergence [3], [4] of the electric potential. These quantities, viewed as local complexity gauges, are used as node selection criteria for interpolating nonlinear functions, given that they introduce nodes that preserve a maximum amount of information. Further, to limit the growth of the interpolation error, the resulting MIR-generated index set is complemented with indices that are selected with a greedy approach, similar to the one used as part of the discrete empirical interpolation method [5]. Our numerical investigations validated the performance of the MIR method in terms of improved accuracy, and without overloading the offline stage of the model reduction framework. We believe that the same information-theoretic / time series analysis approach requires more attention, since it exploits the high-fidelity snapshots and hence, it can be beneficial even for problems with strong nonlinearities that are distributed in a large part of the computational domain.

References

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