ABSTRACT

Model order reduction (MOR) refers to the process of reducing the size of large scale discrete systems with the goal of capturing their behavior in a small and tractable model known as the reduced order model (ROM). ROMs are invariably constructed by projecting the original system onto a low rank subspace that captures the physics for specified range/s of parameter/s. The parameters, say for electromagnetic scattering, can be the frequency of excitation, angle of incidence, and/or material parameters. Thus, ROMs enable fast parameter sweep analysis and quick prototyping.

Historically, a majority of the MOR techniques dealt with systems that are either linear or linearizable. Such techniques were developed around the numerically robust and computationally efficient Krylov subspace methods such as the Arnoldi or the Lanczos algorithm for single input, single output (SISO) systems. For multiple input, multiple output (MIMO) case, the block versions of these algorithms were used. In particular, the Lanczos algorithm could be used to construct a Padé approximation of the original system. Furthermore, since Krylov subspace based ROMs could preserve important attributes of the original system, like passivity, they were specifically popular in large-scale interconnect modeling.

However, the frequency domain finite element method (FEM) (used in this work), in the presence of absorbing boundaries (or perfectly matched layers) and/or losses in the media leads to matrix systems that exhibit nonlinear dependence on the frequency of excitation. One can approximate this nonlinear dependence with a matrix polynomial system through Taylor expansion and linearize the system followed by a projection via Arnoldi (PVA) or Padé via Lanczos (PVL) to construct the ROM. However, linearizations usually increase the system size depending upon the polynomial degree besides having a different sparsity pattern than the matrix polynomial. Alternatively, one can tackle the nonlinearity directly by matching the moments using what is known as asymptotic waveform evaluation (AWE). AWE is inherently an ill-conditioned process. A recent work known as the well-conditioned AWE (WCAWE) improves its conditioning by enforcing implicit orthonormalization

while still matching moments, by introducing some correction terms. However, WCAWE can be cumbersome to implement and appears to be inherently sequential.

This work reports a novel perspective on the AWE space and proposes a parallelizable multilevel Krylov subspace generation technique that improves the accuracy/bandwidth of the ROM even further.

We also introduce a novel adaptation of the Jacobi-Davidson algorithm, which is used to solve nonlinear eigenvalue problems (NLEVP), to target solutions and their derivatives (AWE space) for the matrix system rather than the underlying NLEVP, and formulate its well-conditioned form. By doing so, we enable the use of a new preconditioned iterative solver for AWE.

Finally, noting the bottleneck posed by the reassembly of excitation vector derivatives at the expansion points in certain types of multipoint AWE ROMs, we propose an algorithm to reuse the derivatives, thus saving on the ROM setup time considerably, without sacrificing accuracy.

The efficacy of the proposed algorithms is verified through several practical examples. The work is concluded with pointers to many possibilities for future research, like preconditioners, parallelization and domain-decomposition.