MoRePaS 2015

Model Order Reduction for Magneto-Quasistatic Equations

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Design of complex integrated circuits with electromagnetic devices involves the numerical simulation of Maxwell's equations coupled with the network equations. In magneto-quasistatic problems, the contribution of the displacement currents is neglected compared to the conductive currents. A finite element discretization of the resulting Maxwell equations in the magnetic vector potential formulation leads to a high dimensional nonlinear system of differential-algebraic equations (DAEs)

$$E\dot{x} = A(x)x + Bu, \quad y = Cx$$

with the structured matrices

$$E = \begin{bmatrix} M & 0 \\ X^T & 0 \end{bmatrix}, \qquad A(x) = \begin{bmatrix} -K(a) & X \\ 0 & -R \end{bmatrix}, \qquad B = C^T = \begin{bmatrix} 0 \\ I \end{bmatrix}.$$

In model reduction of DAEs, special care should be taken while approximating the algebraic components and algebraic constraints which restrict the solution to a manifold.

By employing the system structure, we develop an efficient model reduction approach for the magneto-quasistatic DAE system. Our approach is based on transforming this system into the ODE form and applying the proper orthogonal decomposition (POD) [2] combined with the discrete empirical interpolation method (DEIM) [1] for efficient evaluation of the nonlinearity in the reduced-order model. A further reduction in computational complexity can be achieved by using the matrix DEIM for the approximation of the Jacobi matrix. We present an efficient implementation of the matrix DEIM which avoids the vectorization of the snapshot matrices of the Jacobian and significantly reduces the computational cost of the offline phase. Furthermore, we investigate the passivity of the infinite-dimensional problem and the preservation of this property in the semidiscretized system and the POD-DEIM reduced model. Numerical examples will demonstrate the properties of the developed model reduction method.

References

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