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Fully-Implicit / Direct-to-steady-state Solution of FE Formulations for Resistive Magneto-Hydrodynamic Systems*

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Ionized fluids with strong electromagnetic effects occur frequently in nature and are critical for many important technological applications. Examples include stellar interiors, gaseous nebula, the earth's magnetoshpere, and Tokamak and Z-pinch physics. These systems are described by a set of partial differential equations that conserve momentum, mass, charge, and energy along with magnetic flux for the electric and magnetic fields (Maxwell's equations). The resulting magnetohydrodynamics (MHD) equations are strongly coupled, highly nonlinear, and span a large range of time and length scales, making the scalable, robust, and accurate solution of such systems extremely challenging.

In this presentation, we will briefly discuss the development of multiple MHD formulations based on unstructured stabilized finite element methods. The formulations are designed for weak enforcement of the solenoidal constraint, $\nabla \cdot \mathbf{B} = 0$. The formulations include a 2D vector potential formulation, a 3D **B**-field formulation using projection and a 3D **B**-field formulation using variational multi-scale stabilization. The resulting set of nonlinear equations are solved using a fully-coupled Newton-Krylov solver with nonlinear globalization techniques. Linear systems are solved using a multi-level preconditioned GMRES iterative technique. We will present numerical performance, accuracy, and initial scalability studies of the formulations. Additionally we will present an application of our solvers to perform a stability and bifurcation analysis of the hydromagnetic Rayleigh-Bernard problem.

*This work was partially funded by the DOE Office of Science AMR Program, and was carried out at Sandia National Laboratories operated for the U.S. Department of Energy under contract no. DE-ACO4-94AL85000