Efficient Modelling the Triaxial Induction Logging Response to Near-borehole Hydraulic Multi-fractures with a One-element Perfectly Matched Layer and Impedance Transition Boundary Condition

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Hydraulic fracturing is one effective approach to improve the production of unconventional shale oil and gas. To monitor the development of fractures, either acoustic or electromagnetic (EM) techniques are used to characterize the produced fractures. Due to the high attenuation of subsurface medium to electromagnetic waves, only low frequency electromagnetic fields are used to penetrate the deep subsurface. Conventional EM solvers in the low-frequency regime face significant challenges in electromagnetic well logging because: 1. Moving logging tools can be characterized as a fixed EM linear system with variant source vector, and therefore inverting the system matrix directly will be much more efficient than employing iterative solvers, but the direct solvers are generally more memory consuming than the iterative solvers; 2. It is a multiscale problem where the fracture thickness is orders of magnitude smaller than its diameters, producing tremendous meshes and increasing the computational memory largely, if discretizing it volumetrically; 3. It is an open boundary diffusion-like problem which requires appropriate absorbing boundary conditions to truncate the computational domain and absorb the outgoing strongly decaying waves effectively and efficiently to save the computational memory.

In this paper, we develop a discontinuous Galerkin frequency domain (DGFD) method, which incorporates a one-element perfectly matched layer (PML) absorbing boundary condition with the physical domain by the Riemann transmission condition (RTC). The RTC can evaluate the numerical flux correctly while allowing the adjacent meshes non-conformal and equipped with different orders of basis functions. The one-element PML can absorb the strongly decaying waves effectively and efficiently with high order basis functions; the dense hexahedrons can capture the borehole correctly with low order basis functions. The impedance transition boundary condition (ITBC) is introduced to facilitate fracture modeling by approximating them as surfaces. Benefitting from the above memory-saving techniques, the dimensions of the final system matrix are reduced and it can be efficiently solved by the sparse LU direct solver. Numerical examples show that the one-element PML and ITBC based DGFD method can model the near-borehole hydraulic multi-fractures correctly and efficiently.