Hybrid kinetic-MHD modeling of alpha-driven TAEs in the SPARC tokamak

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As the magnetic confinement fusion community prepares for the next generation of fusion devices and burning plasmas, there is still a question of whether fast ions (FIs) will drive MHD instabilities, causing significant redistribution or even loss of FIs, thereby leading to reduced plasma performance and possibly threatening the integrity of the first wall. In this paper, we explore the existence and stability of Toroidicity-induced Alfvén Eigenmodes (TAEs) in the >100 MW, $Q \sim 9-11$ DT-fusion power "Primary Reference Discharge" (PRD) of the SPARC tokamak; the PRD has a relatively low on-axis alpha pressure, $\beta_{\alpha 0} \approx 0.6\%$, due to the high magnetic field strength, $B_0 = 12.2$ T. A scan in toroidal mode number is performed in the vicinity of the estimated "most unstable" modes, $n \approx 5 - 20$, with the linear eigenvalue code NOVA-K and nonlinear initial-value code MEGA. Both codes identify the same (even) n = 10 TAE located near q = 1 with frequency $f \approx 360$ kHz and alpha drive $\gamma/\omega \approx +0.6\%$. While MEGA evaluates this mode to be marginally unstable for the nominal alpha pressure, NOVA-K instead identifies a higher frequency (odd) n = 10 TAE as marginally destabilized; different evaluations of radiative damping are likely the cause of this discrepancy. These results indicate that AEs may be only marginally unstable for the highest performing SPARC PRD, at least for the q profile explored here. They also serve as a starting point for further scans, inclusion of FIs from auxiliary heating systems, and exploration of AE-induced FI transport, as well as a guide for diagnostic measurements of these $n \approx 10$ AEs.