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Physics-model-based Real-time Optimization for the Development of Steady-state Scenarios at DIII-D

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Recent and ongoing experiments on DIII-D demonstrate the potential of model-based real-time optimization for the realization of advanced steady-state scenarios by tightly regulating the q profile and β_N (or the plasma energy W) simultaneously. A primary goal for the DIII-D research program over the next five years is to develop the physics basis for a high q ($q_{\min} > 2$), high β_N, steady-state scenario (fully relaxed plasma state where the current is entirely noninductive) that can serve as the basis for future steady-state burning plasmas. Various approaches are being considered to maximize both the bootstrap current and the noninductive current-drive contributions, so that fully noninductive ($f_{NI} = 1$) discharges can be obtained for several resistive current diffusion times. It is anticipated that the upcoming upgrades to DIII-D, including an additional off-axis neutral beam injection (NBI) system, will provide sufficient auxiliary current drive to maintain fully noninductive plasmas at high β_N. However, much work is still necessary to investigate MHD stability, adequate confinement, and early achievement and sustainment of the steady-state condition. The capability of combined q-profile and β_N control to enable access to and repeatability of steady-state scenarios for $q_{\min} > 1.4$ discharges has been assessed in DIII-D experiments. To steer the plasma to the desired state, a model predictive control approach to both q-profile and β_N regulation numerically solves successive optimization problems in real time over a receding time horizon by exploiting efficient quadratic programming techniques. A key advantage of this control approach is that it allows for explicit incorporation of plasma-state/actuator constraints to prevent the controller from driving the plasma outside of stability/performance limits and obtain, as closely as possible, steady state conditions. Experimental results demonstrate the effectiveness of the real-time optimization scheme to consistently achieve the desired scenarios at predefined times and suggest that control-oriented model-based scenario planning in combination with real-time optimization can play a crucial role in exploring stability limits of advanced steady-state scenarios.

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