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Physics-Model-Based Control of the Plasma State Dynamics for the Development and Sustainment of Advanced Scenarios in DIII-D

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DIII-D experiment results are presented to demonstrate the potential of integrated physics-model-based q-profile and βN control for the systematic development and sustainment of advanced scenarios. Both simulations and experiments demonstrate improved control performance relative to unoptimized preprogrammed control, by utilizing a combined feedforward+feedback scheme. At the core of the control scheme is a nonlinear, physics-based, control-oriented model of the plasma dynamics valid for H-mode scenarios. A partial differential equation model of the
q-profile dynamics is developed by combining the poloidal magnetic flux diffusion equation with physics-based models of the electron density and temperature profiles, the plasma resistivity and the noninductive current sources (both auxiliary and bootstrap). The plasma internal energy (related to βN) dynamics are modeled by a volume-averaged energy balance equation. Firstly, a nonlinear, constrained optimization algorithm to design feedforward actuator trajectories is developed with the objective of numerically complementing the traditional trial-and-error experimental effort of advanced scenario planning. The goal of the optimization algorithm is to design actuator trajectories that steer the plasma to a target state (q-profile and βN) at a predefined time during the discharge, such that the achieved state is stationary in time, subject to the plasma dynamics (described by the physics-based models) and plasma state and actuator constraints. Secondly, integrated feedback controllers are designed to track a target q-profile and βN evolution with the goal of rejecting the effects of external plasma disturbances and adding robustness to the control scheme. The feedback controllers are synthesized by embedding both static and dynamic physics-based plasma response models into the control design and to be robust to uncertainties in the electron density, electron temperature and plasma resistivity profiles. The algorithms use the heating/current-drive system and total plasma current as actuators to control the plasma dynamics. Finally, experimental and simulation results are presented to demonstrate the capabilities of the optimized actuator trajectories and feedback controllers to control the plasma dynamics in DIII-D advanced scenarios.

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