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Proximity-to-Instability Control and Cross-Machine VDE Stability Metrics on DIII-D and KSTAR

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ITER will require exceptionally low disruptivity while pushing the limits of plasma performance. Ensuring robust stability will require a comprehensive strategy, and must include the continuous regulation of the proximity to stability and controllability limits, also called "Proximity Control."DIII-D has been developing a Proximity Control architecture [1] which modifies control targets and actuator constraints based on stability metrics in real-time. The system has been applied and tested for robust Vertical Displacement Event (VDE) avoidance and preventing un-intended H-L back-transitions. Despite a pre-defined (intentionally) increasing trajectory for elongation (κ) set to induce a VDE, the Proximity Control algorithm successfully over-rode original control inputs when growth rates exceeded a threshold for intervention and adjusted plasma shaping targets (both κ and plasma distance to the inner wall) to ensure stability. The controller regulated the VDE growth-rate at 800 rad/s for more than 3s [1]. Unintended H-L back-transition protection integrated with β_N feedback control was demonstrated with the real-time modification of the minimum input power based on two different real-time stability monitors. The first monitored the radiated power, and the second used a machine learning (ML) predictor for the likelihood of H-/L-mode. Both tools prevented an H-L back-transition with a user-set, low β_N feedback target trajectory, which would have otherwise led to reduced heating and back-transition. The J|| gradients in the edge of ITER Baseline Scenario plasmas have been identified as indicators of tearing mode stability [2]. Recent experiments are described, which demonstrate first tests and limited controllability of edge gradients in J|| in the ITER Baseline Scenario using real-time adjustments in the plasma triangularity and squareness.
Experiments on KSTAR have diagnosed the limits of its vertical control [3-4] using machine-scalable metrics, including measured VDE growth rates and the maximum Z-excursion that the vertical control system can restore (dZmax). A maximum κ > 2.2 was sustained for more than 3s in experiment. Triggered VDEs were used to directly diagnose the vertical growth rates, measured to reach up to 300 rad/s at these high elongations. dZmax was diagnosed under two different ELMing conditions: one with slower, larger ELMs, and the second with faster, smaller ELMs. dZmax was measured to be 2cm and 2.3cm in each of these conditions, respectively. These correspond to machine-scalable metrics of dZ_max/⟨dZ⟩_noise˜15x-10x and dZ_max/a_minor˜4.5-5%, consistent with previous studies on DIII-D and similar to expectations of marginal stability on ITER [5].
In future work, the DIII-D Proximity Control algorithm will be expanded to addition disruption prevention applications as well as ported to KSTAR for direct cross-device studies. On DIII-D, the controller has been integrated with the Disruption Prediction using Random Forests (DPRF) [6] interpretable ML algorithm, to be tested in upcoming experiments.
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[2] F. Turco 2018 NF 58 106043 [4] D.A. Humphreys 2009 NF 49 115003
[6] S.-H. Hahn 2020 FED 156 111622 [5] C. Rea 2019 NF 59 096016

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