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On the validation of dynamic models for (exhaust) control on DEMO class devices; a comparison in multiple fidelities to experiments in TCV

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The exhaust in a DEMO-class tokamak requires continuous operation in detachment [1]. In highly radiative detached regimes edge-localized modes (ELMs) may be suppressed, reducing reliance on RMP coils for ELM suppression. However, these regimes are close to radiative plasma limits which trigger disruptions that threaten machine-integrity. In stark contrast to conventional reactors, this necessitates a control system (not just for the exhaust) that guarantees operation within safety-critical limits in presence of disturbances. Such guarantees rely on dynamic models of the entire plasma that: 1) capture the response to actuators and disturbances; 2) connect to reactor relevant sensors; 3) describe safety critical limits; 4) scale to DEMO size reactors.

In this contribution we validate the dynamics in multiple physics-based models using a system-identification experiment in the TCV tokamak [2]. This data class has proven its use in controller design, providing guarantees for stability and performance [3]. We compare: 1) TCM a three chamber model simulating 0D reservoirs [4]; 2) DIV1D using reservoirs combined with a 1D scrape-off layer [5]; and 3) SOLEDGE3X-EIRENE as the high-fidelity 2D plasma-edge simulator [6]. We find that the coupling to a core reservoir and a realistic time-scale for neutrals to ionize allows the models to align with the measurements. Similar validations on other devices (using existing data) should be prioritized over predicting behavior on non-existing devices.

To enable model-based control for DEMO-class devices, the challenge for integrated modeling is to shift from interpretations (on isolated domains) to full device time-dependent simulations that mimic the complexity faced when operating DEMO. We should prioritize quantification of errors in solutions with respect to the operational window, disturbances and control-relevant dynamics. Physics-based models should be used to design and demonstrate controllers (that take advantage of real-time data) with operational guarantees jointly for core and exhaust. To be clear, demonstration means running high-performance detached discharges without ELMS or disruptions with the 99% reliability required in DEMO, ARC, STEP, and ITER.

References

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