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Real-time model-based plasma state estimation, monitoring and integrated control in TCV, ASDEX-Upgrade and ITER

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To maintain a high-performance, long-duration tokamak plasma scenario, it is necessary to maintain desired profiles while respecting operational limits. This requires real-time estimation of the state of the profiles, monitoring of their evolution with respect to predictions and known limits, and their active control within a desired envelope. Model-based techniques are particularly suitable to tackle such problems due to the nonlinear nature of the processes and the tight coupling among the various physical variables. Control-oriented models required for such techniques have been recently developed for particle, temperature and current density profiles. These are implemented in the RAPTOR control-oriented physics-based tokamak simulation code. RAPTOR is capable of tokamak discharge plasma profile evolution in real-time. It includes the main nonlinear dependencies in the profiles, effects of sawteeth and NTMs, as well as all relevant sources, sinks, heating and current drive actuators.

We present various new applications of control-oriented profile evolution models for TCV, ASDEX-Upgrade and ITER. Real-time estimation of profiles is performed on TCV and ASDEX-Upgrade by combining diagnostic data with real-time model-based predictions in a dynamic state observer. By monitoring the differences between measurements and predictions, unexpected signals can be determined that may come from diagnostic faults, actuator failures or unexpected evolution of the plasma itself. These strategies for model-based real-time scenario monitoring are tested on TCV and ASDEX-Upgrade and can provide a first line of defense against easily predictable disruptions that have a clear origin, minimizing the use of last-resort disruption mitigation measures.

To maintain the plasma in the desired state for the duration of the discharge, profile controllers are designed that can deal with varying constraints in the plasma and actuators as well as provide ahead-of-time warning of constraint violations. At the same time, a real-time actuator allocation algorithm performs a prioritization of control objectives and assigns resources to each controller. Simulations of combined plasma q-profile, temperature, and NTM control for an ITER scenario are shown, representing a first example of a coupled, resource-aware control scheme that will benefit future tokamak operation.

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Author: Dr FELICI, Federico (Eindhoven University of Technology)

Co-authors: Ms TEPLUKHINA, Anna (EPFL-SPC); Mr MALJAARS, Bert (Eindhoven University of Technology); Dr PIRON, Chiara (Consorzio RFX); Dr RAPSON, Chris (IPP Garching); Dr GALPERTI, Cristian (EPFL-SPC); Dr

HOGEWEIJ, Dick (DIFFER); VAN DEN BRAND, Hugo (DIFFER); Dr MORET, Jean-Marc (EPFL-SPC); Dr CITRIN, Jonathan (DIFFER); Dr GIANNONE, Louis (IPP Garching); Prof. STEINBUCH, Maarten (Eindhoven University of Technology); Prof. DE BAAR, Marco (DIFFER); Mr SCHEFFER, Mark (Eindhoven University of Technology); Dr WILLENSDORFER, Matthias (IPP garching); Dr SAUTER, Olivier (EPFL-SPC); Mr KUDLACEK, Ondrej (Consorzio RFX); Dr PIOVESAN, Paolo (Consorzio RFX); Dr NOUAILLETAS, Remy (CEA-IRFM); Dr CODA, Stefano (EPFL-SPC); Mr BLANKEN, Thomas (Eindhoven University of Technology); Dr VU, Trang (CEA-IRFM); Dr TREUTTERER, Wolfgang (IPP Garching)

Presenter: Dr FELICI, Federico (Eindhoven University of Technology)

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