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Control of NTMs and integrated multi-actuator control on TCV

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Detailed experiments have been performed on TCV with its flexible electron cyclotron heating/current drive system to investigate reliable and efficient control of NTMs. For example, a novel sinusoidal sweeping technique has been studied in detail and we have shown for the first time that it is efficient for both NTM stabilization and preemption. This method is important for future devices as it relaxes the demand on the accuracy of the mode location estimation and the beam deposition calculation, and circumvents the need for extra diagnostics or many shots for tuning. Comparison between NTM preemption and stabilization has been achieved with sweeping and it shows that preemption can be more than twice as efficient as stabilization in terms of the necessary power.

The reliable, efficient and generic control of NTMs allows the development of a controller working for all the scenarios and independent of the specialties of TCV, facilitating the integration with other real-time (RT) algorithms. RT control of NTMs, beta and model-estimated q profiles have been achieved simultaneously on TCV for the first time with a generic integrated control framework that consists of a hierarchy of state estimation/prediction, plasma event monitoring, supervision, high-level (HL-) actuator management (AM), generic controllers and low-level (LL-) AM. In an integrated control test, RT diagnostics are used with RT simulations to reconstruct the plasma state. We will show how RT analyses of magnetic signals are used to provide details of the mode, the RAPTOR observer to reconstruct electron temperature and q profiles, the RAPDENS-observer to generate density profiles and RT-TORBEAM to calculate beam depositions. This information is then used by the plasma event monitor to produce a finite-state representation of the plasma state based on user-defined thresholds. The supervisor prioritizes various tasks, activates relevant controllers and interfaces with a generic control layer. In this layer, controllers send requests for each task to the HL-AM that optimizes the actuator allocation and sends back the actuation capability to the controllers and the LL-AM. The LL-AM sends controller commands to the tokamak-specific actuators. Importantly, the control layer has been made tokamak agnostic to facilitate its reuse in other devices and to provide a layer of abstraction for operators.

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