Real-time physics-based simulation and optimal control of tokamak plasma profiles

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Real-time simulation of plasmas, numerically evolving the plasma in a computer at the same time as physically evolving it in the tokamak, is a key requirement for advanced tokamak operation in view of ITER and represents a challenging domain at the frontier between tokamak simulation and operations. On TCV, exploiting the capabilities of a new digital control system, we have recently implemented a transport code capable of simulating the evolution of the poloidal flux distribution in real-time during a plasma shot, giving accurate estimates of the q profile with time steps of 1ms. A new lightweight 1D plasma transport code called RAPTOR (RApid Plasma Transport simulatOR) was developed for this purpose. It uses real-time acquired measurements to deduce temperature and density profiles and solves the partial differential equation describing the physics of poloidal flux profile diffusion including the effects of non-inductive and bootstrap current. The real-time simulator has been integrated with a feedback controller of the plasma temperature and current profiles using the multi-launcher ECH system, and successfully tested the controller during plasma discharges.

The RAPTOR code used in the real-time interpretative simulations described above can also be used off-line in predictive mode, where it includes a simulation of the electron temperature profile together with the flux profile. Uniquely, it returns not only the plasma response in time to the actuator inputs, but also the first-order sensitivities of the plasma response to these inputs. This talk describes how this predictive code has been embedded in a nonlinear, constrained numerical optimization scheme to determine (off-line) the optimal time trajectories of plasma current and auxiliary power to obtain the desired plasma profiles at a given time. This provides a sound basis for feedback control of the profiles during both transient and steady-state plasma phases, which is the subject of exploration in the current TCV campaign, and opens up multiple interesting avenues for further research.