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Robust Burn Control in ITER Under Deuterium-Tritium Concentration Variations in the Fueling Lines

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Tight regulation of the burn condition in ITER has been proven possible even under time-dependent variations in the fuel concentration by the use of robustification techniques. One of the most fundamental control problems arising in ITER and future burning-plasma tokamaks is the regulation of the plasma temperature and density to produce a determined amount of fusion power while avoiding possible thermal instabilities. Such problem, known as burn control, will require the development of controllers that integrate all the available actuators in the tokamak. Moreover, the complex dynamics of the burning plasma and the uncertain nature of some of its magnitudes suggest that nonlinear, robust burn controllers will be necessary. Available actuators in the burn control problem are auxiliary power modulation, fueling rate modulation, and impurity injection. Also, recent experiments in the DIII-D tokamak have shown that in-vessel coil-current modulation can be used for burn control purposes. The in-vessel coils generate non-axisymmetric magnetic fields that have the capability to decrease the plasma-energy confinement time, which allows for regulating the plasma energy during positive energy perturbations. In this work, in-vessel coil-current modulation is included in the control scheme, and it is used in conjunction with the other previously mentioned actuators to design a nonlinear burn controller which is robust to variations in the deuterium-tritium concentration of the fueling lines. Furthermore, fueling rate modulation is not only used to control the plasma density, but also to control the plasma energy if necessary by means of isotopic fuel tailoring. Isotopic fuel tailoring is a particular way of fueling the burning plasma which allows for reducing the fusion power produced and, therefore, also gives the opportunity to decrease the plasma energy when needed. The model-based nonlinear controller is synthesized from a zero-dimensional model of the burning-plasma dynamics. A nonlinear simulation study is used to illustrate the successful controller performance in an ITER-like scenario in which unknown variations of the deuterium-tritium concentration of the fueling lines are emulated.

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