Model predictive control of ITER plasma current and shape using SVD

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Overview

- Plasma Current and Shape Controller (PCSC) for the flat-top phase of ITER Scenario 1
- Fast Model Predictive Control (MPC) using a dual Fast Gradient Method (dFGM) quadratic programming (QP) solver
- The number of plasma shape geometrical descriptors (output space dimension) reduced using Singular Value Decomposition (SVD)

Output space reduction using SVD

The output dimension is reduced considering the steady-state relation between the poloidal field & central solenoid currents $I_p$ and the plasma shape geometrical descriptors $g$ using SVD, where the aim is to achieve a minimum weighted tracking error $(g - g_{\text{ref}})Q(g - g_{\text{ref}})$ in the steady state, while also striving towards low steady-state control effort $(I_p - I_{p,\text{ref}})R(I_p - I_{p,\text{ref}})$.

Solving QP problems for MPC using dFGM

In MPC, a QP optimisation problem must be solved in each time step of the algorithm, which poses a problem with large-scale multivariable systems with fast dynamics. Using complexity reduction techniques for MPC and code optimisation, peak computation times under 7 ms were achieved with the dFGM algorithm, which is able to consider soft state constraints for the enforcement of constraints.

Simulation closed-loop performance evaluation

The proposed SVD-based FMPC PCSC was compared to a reference CREATE v2d0 controller based on SVD and multivariable PID with local models corresponding to the operating points of the ITER Scenario 1:
- $t = 80$ s,
- $t = 90$ s,
- $t = 520$ s

with the following disturbances:
- Minor Disruption,
- Uncontrolled ELM,
- L-H Transition,
- H-L Transition,
- Vertical Displacement Event,
- using the same Vertical Stabilisation controller.

Performance Measures:
- maximal gap displacement from the reference,
- sum of gap displacements at the end of simulation,
- average of RISE value for all gap displacements,
- smallest gap of plasma shape to the chamber wall,
- maximal plasma current displacement $\Delta I_p$,
- RISE value of $\Delta I_p$,
- displacement of the closest $I_p$ from its bound,
- sum of $I_p$ displacements from the equilibrium value,
- sum of RISE of all $I_p$ displacements from equilibrium,
- maximal $I_p$ displacement from equilibrium,
- peak value of total power consumption,
- RISE value of total power consumption,
- sum of RISE of all $V_p$ voltages.
* Root of Integral Square Error

Conclusions

The SVD-based MPC PCSC is computationally feasible for ITER, with peak computation time under 7 ms using a dFGM QP solver.

The performance evaluation in simulation of specific disturbances in different operating points of ITER Scenario 1 generally shows better performance in terms of transient peak, settling time and the steady-state offset of gaps, and a much better performance in tracking of the plasma current than the reference scheme with most disturbances. It can avoid superconductive current saturations, which is not the case with the reference scheme, and in some cases shows better performance regarding voltage saturations.