Plasma Current and Shape Control for ITER using Fast Online MPC

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***Abstract*–In this work we explore the practical feasibility of using MPC for PCSC in the ITER tokamak, employing complexity reduction techniques and recently developed fast on-line quadratic programming (QP) optimization methods. A survey of the available QP methods suitable for the on-line solution of MPC optimization problems is given, with emphasis on first-order methods, which have been recently considered as prime candidates for fast online MPC control. Using a modification of the QP solver QPgen, a five-fold speed-up compared to the state-of-the-art commercial solver CPLEX was achieved, with peak computation times below 10 ms using a four-core Intel processor.**

I. Introduction

In a magnetically confined tokamak reactor, the Plasma Current and Shape Controller (PCSC) is the component of Plasma Magnetic Control (PMC) that commands the voltages applied to the poloidal field coils, to control the coil currents and the plasma parameters, such as the plasma shape, current, and position. The PCSC acts on the system pre-stabilized by the Vertical Stabilization controller, which is another PMC component. The challenge of PMC is to maintain the prescribed plasma shape and distance from the plasma facing components, in presence of disturbances, such as H-L transitions or ELMs, and to changes of local dynamics in different operating points.

Model Predictive Control (MPC) is an established advanced process control technique in the process industry. It has gained wide industrial acceptance by facilitating a systematic approach to control of large-scale multivariable systems, with efficient handling of constraints on process variables and enabling plant optimization. These advantages are considered beneficial for PCSC, and potentially also for other control systems of a tokamak. The main obstacle to using MPC for control of such processes is the restriction of the most relevant MPC methods to processes with relatively slow dynamics due to the long achievable sampling times, because time-consuming on-line optimization problems are being repeatedly solved at each sample time of the CSC control loop for determining control actions.

In this work we explore the practical feasibility of using MPC for PCSC in the ITER tokamak, employing complexity reduction techniques and recently developed fast on-line quadratic programming (QP) optimization methods. A survey of the available QP methods suitable for the on-line solution of MPC optimization problems is given, with emphasis on first-order methods, which have been recently considered as prime candidates for fast online MPC control. MPC is applied to a simulation model, where PMC makes use of a combination of ohmic in-vessel coils and superconducting poloidal field coils. The prototype MPC controller [1, 2] is based on the control scheme of [3].

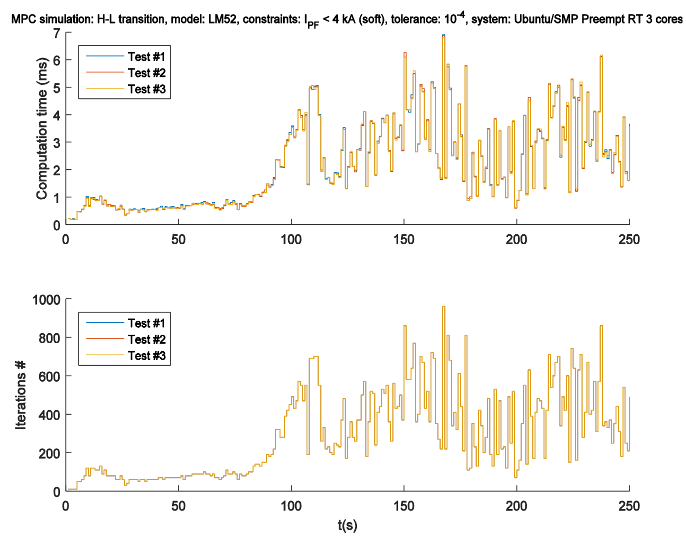

Fig. 1. Computational demand of MPC PCSC using the dual FGM method with complexity reduction in simulation of a H-L transition with soft constraints on poloidal field and central solenoid coil currents $\mathbf{I}_{PF}$ < 4 kA. Top: computation time (ms), bottom: number of iterations; three repeated simulations with small variation in computation time but the same number of iterations are shown.

Fig. 1 shows an example of the computational demand of MPC PCSC using the dual FGM method with complexity

Manuscript received January 31, 2016. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was in part supported by Slovenian Research Agency (P2-0001).

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reduction in simulation of an H-L transition running on 3 cores of an Intel i7-2600K based system with Ubuntu Linux and SMP Preempt RT kernel. For comparison, the computational demand of a similar simulation using the commercial CPLEX solver with complexity reduction in Fig. 2 and without complexity reduction in Fig. 3 are shown. Fig. 4 displays the main control signals in the corresponding simulations with complexity reduction (solid lines) and without complexity reduction (dashed lines).

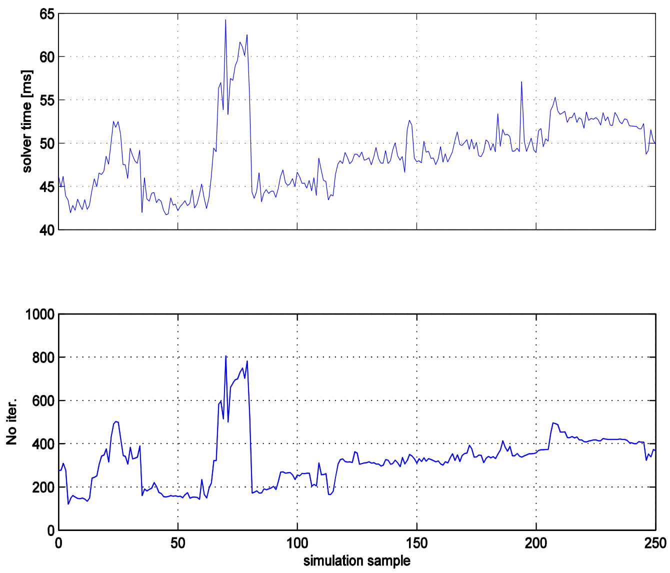

Fig. 2. Computational demand of MPC PCSC using the CPLEX solver with complexity reduction in simulation of a H-L transition with soft constraints on poloidal field and central solenoid coil currents $\mathbf{I}_{PF} < 4$ kA. Top: computation time (ms), bottom: number of iterations.

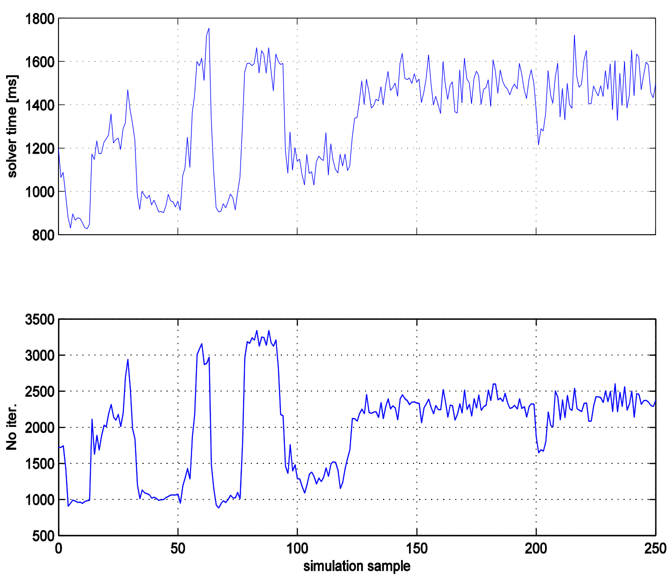

Fig. 3. Computational demand of MPC PCSC using the CPLEX solver without complexity reduction in simulation of a H-L transition with soft constraints on poloidal field and central solenoid coil currents $\mathbf{I}_{PF} < 4$ kA. Top: computation time (ms), bottom: number of iterations.

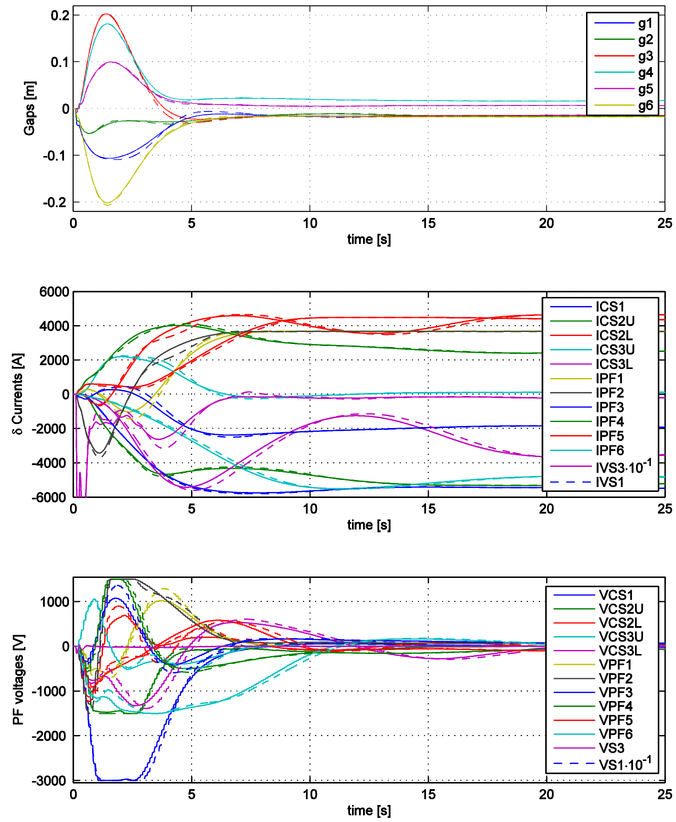

Fig. 4. Process signals of MPC PCSC with (solid lines) and without (dashed lines) complexity reduction in simulation of a H-L transition with soft constraints on poloidal field and central solenoid coil currents IPF < 4 kA. Top: gaps, middle: coil currents, bottom: coil voltages. For all signals, the deviations from the nominal operating point is displayed.

II. Conclusion

Using a modification of the QP solver QPgen [4], a five-fold speed-up compared to the state-of-the-art commercial solver CPLEX was achieved, with peak computation times below 10 ms using a four-core Intel processor in a real-time Linux environment. This is already considered sufficiently fast for the 100 ms sample time estimated to be suitable for the ITER CSC MPC controller.

Acknowledgment

We thank Cosylab for assistance with real-time testing of the algorithms.

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