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Tokamak-agnostic actuator management for integrated control

N.M.T. Vu[1], T.C. Blanken[2], M. Kong[1], E. Maljaars[2], F. Felici[1], C. Galperti[1], O. Sauter[1]
and the TCV[3] team and the MST1 team[4]

[1] Ecole Polytechnique Fédérale de Lausanne, Swiss Plasma Center, [2] Eindhoven University of Technology, Department of Mechanical Engineering, [3] See the author list of S. Coda et al., 2017 Nucl. Fusion 57 102011, [4] See the author list of H. Meyer et al., 2017 Nucl. Fusion 57 102014

trang.vu@epfl.ch

In order to satisfy the global physics goals in complex experiments on long-pulse tokamaks, a plasma control system (PCS) should aim to simultaneously reach multiple control objectives (control tasks) with a limited set of actuators [1,2]. This work proposes a generic PCS scheme based on a so-called task-based approach to achieve this difficult objective. In this approach, generic control tasks are defined from the physics goals. A plasma supervisor and actuator manager are then used to handle the considered tasks, using generic actuator resources and controllers. This leads to a clear separation of the PCS into two layers: a tokamak-agnostic layer and an interface layer. This approach has several advantages. Firstly, it allows the operators to define the control tasks independently from the details of the controllers that execute these tasks. Secondly, the tokamak-agnostic layer can be easily adapted to other tokamaks regardless the complexity of the tokamak subsystems, while only the interface layer should be changed for each tokamak. Furthermore, the standardized interface of the controllers with the actuator manager grants the flexibility to add new controllers to the scheme as well as to develop control algorithms without needing to know the detail of a specific tokamak's diagnostics and actuators.

A general overview of the system and its applications is presented in [3,4,5]. Here we focus on the tokamak-agnostic layer (Fig.1) featuring the plasma state monitor and supervisor, actuator manager (AM) and controllers. From the physics goals, various control tasks are determined and communicated to the PCS via the user interface. The supervisor, based on the plasma and actuator states from the interface layer, makes the decision on how to continue the discharge by activating and prioritizing relevant tasks. Solving an optimization problem, the AM assigns actuator resources to each active task according to their priorities, the actuator states and the resource requests coming from various controllers. The controllers request the resources they need to fulfill their given tasks. After receiving the assigned resources from the AM, they execute their control laws and send their commands to the AM. The commands to actuators are then sent to the interface layer to be converted into the specific actuator commands.

The developed PCS scheme has been implemented on TCV. First results are shown in (Fig.2), where integrated control of beta and neoclassical tearing mode (NTM) are demonstrated. A central heating and co-current drive (H&co-CD) task is activated at the beginning of the discharge in order to establish the plasma to the operational equilibrium and eventually create an NTM. Electron cyclotron (EC) H&CD with two EC launchers *L4* and *L6* is available for this test. At the beginning Task 1 (H&co-CD) is the only activated task thus gets the highest priority defined by the supervisor (Fig.2a) and receives both *L4* and *L6* from the AM (Fig.2b). As Task 2 (NTM stabilization) is activated when an NTM is detected (Fig.2f) and Task 3 (beta control) is activated by the activation time window, the priorities change and so does the assignment of launchers. Fig.2d and Fig.2e show the powers and positions of these launchers, while Fig.2c presents the real-time estimated beta following quite well its reference when Task 3 has the highest priority and the actuator powers are not saturated.

The tokamak-agnostic layer is also applied to an ITER test to deal with larger number of tasks and actuators [4] and is ready to be tested on other tokamaks.

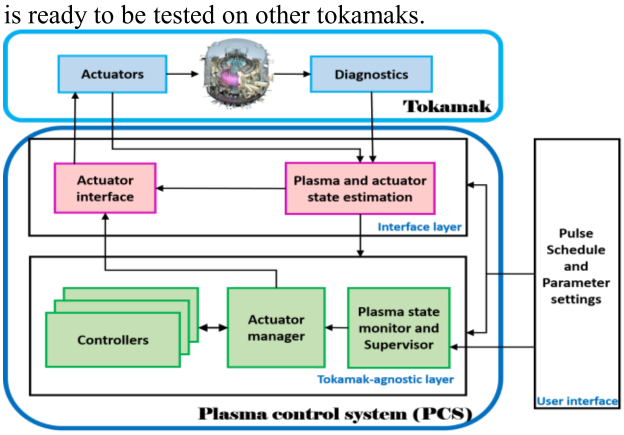

Figure 1 : Generic PCS architecture

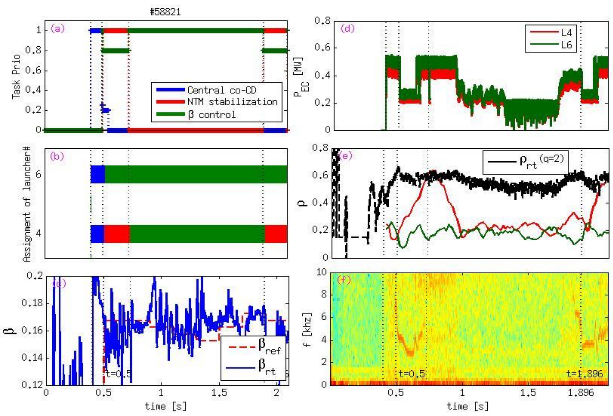

Figure 2 : Result of an integrated control test on TCV

References

[1] Maljaars, E. et al., Fusion Eng. Design 122 (2017)

[2].C. Rapson et al, Fusion Eng. And Design 96 (2015)

[3] M. Kong, et al., AAPPSDPP. (2018)

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