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A simulation environment for ITER PCS development

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HIGHLIGHTS

- Describes task to develop simulation tool to aid development/testing of ITER PCS.
- Requirements and use cases and preliminary architecture have been delivered.
- Detailed design is now being developed.
- Provides overview of use cases and requirements.
- Provides overview of architecture and status of development.

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ABSTRACT

A simulation environment known as the Plasma Control System Simulation Platform (PCSSP), specifically designed to support development of the ITER Plasma Control System (PCS), is currently under construction by an international team encompassing a cross-section of expertise in simulation and exception handling for plasma control. The proposed design addresses the challenging requirements of supporting the PCS design. This paper provides an overview of the PCSSP project and a discussion of some of the major features of its design. Plasma control for the ITER tokamak will be significantly more challenging than for existing fusion devices. An order of magnitude greater performance (e.g. [1,2]) is needed for some types of control, which together with limited actuator authority, implies that optimized individual controllers and nonlinear saturation logic are required. At the same time, consequences of control failure are significantly more severe, which implies a conflicting requirement for robust control. It also implies a requirement for comprehensive and robust exception handling. Coordinated control of multiple competing objectives with significant interactions, together with many shared uses of actuators to control multiple variables, implies that highly integrated control logic and shared actuator management will be required. It remains a challenge for the integrated technologies to simultaneously address these multiple and often competing requirements to be demonstrated on existing fusion devices and adapted for ITER in time to support its operational schedule. We describe ways in which the PCSSP will help address these challenges to support design of both the ITER PCS itself and the algorithms that will be implemented therein, and at the same time greatly reduce the cost of that development. We summarize the current status of the PCSSP design task, including system requirements and preliminary design documents already delivered as well as features of the ongoing detailed architectural design. The methods being incorporated in the detailed design are based on prior experience with control simulation environments in fusion and on standard practices prevalent in development of control-intensive industrial product designs.

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1. Introduction

The high cost and limited number of discharges planned for ITER, as well as the constraints imposed by its nuclear mission, imply both minimal time for scenario and control tuning and a greater

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level of confidence needed in discharge performance prior to execution [1,2]. The use of simulation for control development and verification has been well-established in research and commercial applications to support both of these requirements [3–5]. Several operating tokamaks have made significant use of simulation tools in the development of control algorithms or key components of plasma control systems themselves [6–13]. The broad success of this approach, both commercially and in the fusion community, led to an IO-funded task to develop such a simulation tool, known as the Plasma Control System Simulation Platform (PCSSP), to aid in development and testing of the ITER Plasma Control System. The scope of the current project is limited to deployment of a demonstration prototype environment with selected components. It is envisioned that this prototype may be extended in subsequent efforts to provide a fully capable control simulation tool to also support ITER machine/system design and configuration evolution and discharge scenario development, and to support plant troubleshooting during operations.

A draft of requirements and use cases [14] and a preliminary architecture definition [15] have been delivered and a detailed design addressing a subset of these requirements [16] is now being developed. At the end of 2013, the design and a prototype implementation will be delivered.

2. The vision for PCSSP

The PCSSP is envisioned as a system of components including a computational framework (referred to as a Control Simulation Environment, CSE) in which multiple simulation modules can be implemented, to which external processes can be connected, and which can support input and output interfaces for programming the simulation and interpreting results. The principal goal of ITER PCS development and testing requires a simplified PCS connected to a simplified simulated Plant (system to be controlled), both implemented within PCSSP. Matlab/Simulink has been chosen as the host environment.

PCSSP will provide a number of capabilities that can substantially reduce the time and cost of PCS development, which can be best understood by outlining the steps in this development.

1. Develop and test ITER PCS architecture,
2. Develop and test ITER control algorithms,
3. Implement in real-time code and test,
4. Deploy in ITER operation.

It is expected that Step 1 will be performed only once, but it may not be fully complete until sometime after ITER begins operation. Steps 2–4 will be repeated many times during the ITER lifetime as new control capabilities are developed and brought on-line. PCSSP is envisioned to play a key role in each step but the last.

The ITER PCS will incorporate several architectural features common in operating devices as well as two functions, exception handling (EH) and actuator sharing, that require a level of sophistication not yet demonstrated. PCSSP provides a method for prototyping and evaluating candidate architecture and controller solutions with minimal coding effort. In particular, the Plant simulation will contain an event generator (EG) module that can trigger simulated performance-challenging plasma and hardware events (known as *exceptions*) during control simulation, to evaluate the ability of the EH to handle them [17]. It will also contain a model of the Central Interlock System (CIS), which can be used to test the interaction of the PCS and CIS in responding to events occurring in the Plant [18].

Controller development is facilitated through use of control design *toolboxes* available for Matlab and use of Simulink for controller implementation, debugging, gain tuning, and evaluation of control performance and robustness via simulation.

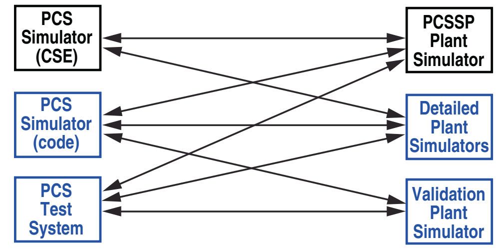

Fig. 1. Expected connections of PCS and plant simulators for closed-loop simulation. Blue blocks indicate objects external to PCSSP. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

When satisfied with controller performance following the initial design and simulation process, the Simulink *Embedded Coder* can generate real-time capable C code versions of the algorithms, to incorporate into the PCS. The actual ITER PCS can then be connected to the plant simulation to evaluate both performance and correctness of implementation via closed loop simulation. Inadequate performance can be remedied through modification of the algorithm in the Simulink model or via hand-tuning of specific portions of the generated code. If hand-tuning is required, the customized code can be inserted as a model block into the Simulink model using the Simulink S-function technology.

3. Key use cases and requirements

The Requirements document [14] details the use cases and requirements for the PCSSP, which currently focuses on simulation. Almost all expected simulation use cases can be summarized by the following sequence of actions:

1. Select a version of PCS to be used (e.g., simulated or actual).
2. Select a version of Plant to use (Fig. 1).
3. Define PCS configuration data, including the ITER pulse schedule.
4. Define configuration parameters that customize plant simulation modules.
5. Define PCS initial state to begin simulation.
6. Define Plant initial state to begin simulation.
7. Connect the PCS and Plant objects (both can be in PCSSP or one can be external).
8. Initiate execution of the simulation.
9. Monitor the simulation.
10. Terminate the simulation.
11. Archive the simulated data.
12. Analyze the simulated data.

Variability in choices of components and detailed actions depend on the stage of PCS development (Fig. 1). The PCS function may be implemented by a simulated PCS in the CSE, actual PCS code running on simulation (non-real-time) computers, or PCS code running on PCS realtime hardware. Algorithm development can use the simplified PCSSP Plant, while more detailed testing and eventual validation of ITER pulse schedules require more accuracy.

Since simulations will be used to evaluate effectiveness of controllers for ITER, plant models used in simulation must be predictive, i.e., responses seen in simulation must be reflected in similar responses seen in physical plasma operation. To gain this confidence, PCSSP will support model validation efforts by providing the capability to execute simulations of currently operating devices as well as ITER and to access experimental data from those devices for comparison with model predictions. Equally important,

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