Fusion Engineering and Design 89 (2014) 523–528

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Event generation and simulation of exception handling with the ITER PCSSP

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ARTICLE INFO

Article history:
Received 24 May 2013
Received in revised form 25 April 2014
Accepted 28 April 2014

Keywords:
Plasma control
Simulation
Exception handling

ABSTRACT

The plasma control system simulation platform (PCSSP) for ITER shall support the analysis and development of methods to be used by the ITER plasma control system (PCS) for handling exceptions to optimize pulses and assist in machine protection. PCSSP will permit to investigate physical and technical events, such as component failures, control degradation, operation domain excess, plasma state bifurcation or instabilities, and interlock activity. Serving that purpose, the plasma, actuator, diagnostics and PCS simulation modules in PCSSP will be enhanced to compute nominal and off-normal data. Configured by an event schedule, an event generator will orchestrate the activation and manipulate the characteristics of such off-normal computation. In the simulated PCS exceptions will be handled in a pulse supervision layer operating on top of the pulse continuous control (PCC) feedback loops. It will monitor events, decide on which exceptions to respond, and compute new control references to modify PCC behavior. We discuss basic concepts for the event generation in PCSSP, and a preliminary architecture for exception handling in PCS, and show how these will be configured with event and pulse schedules.

1. Introduction

The ITER project aims at demonstrating sustained and stable burn of a thermonuclear plasma during long discharges. Such operation domains are not accessible with present machines, and require not only a well-designed plant and technical components, but need also a much more sophisticated active control. The ITER CODAC environment shall provide instrumentation and control functionality to operate the plant at Cadarache [1]. A core application of CODAC is the plasma control system (PCS), which drives a dozen of actuator plant systems for heating, fuelling and shaping of the plasma, and reads measured and evaluated data about the plasma and plant state from tens of diagnostic plant systems.

The mandate of PCS not only covers to establish the desired plasma parameters during the nominal evolution of the discharge [2]. A novel requirement for ITER PCS will be to maximize the scientific use of the device, i.e. dynamically optimize control methods in an investigation to improve plasma quality, or in case the results should not be satisfactory then schedule an alternate investigation to make best use of the long pulses. Another novel PCS task with top priority is to assist in investment protection, i.e. actively avoid violation of pulse control allowables which would trigger the central interlock system (CIS), or in case of a CIS alarm assist that system in handling complex physics situations like runaways or disruptions and terminate the discharge while minimizing stress and risk [3].

Such novel requirements demand for an ability of PCS to modify control schemes in real-time depending on plasma and plant state. ITER intends to investigate and optimize such dynamic schemes with simulation methods, which have already proven valuable for the development of continuous control in various Tokamaks [4–9].

Requirements, use cases and the preliminary architecture for the ITER plasma control system simulation platform (PCSSP) were presented in [10]. In this paper we will focus on how PCSSP is enhanced to simulate modification of control schemes in PCS: we will summarize the basic concepts of PCSSP (Section 2), outline how PCSSP can simulate occurrence of events (Section 3), propose a

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http://dx.doi.org/10.1016/j.fusengdes.2014.04.068

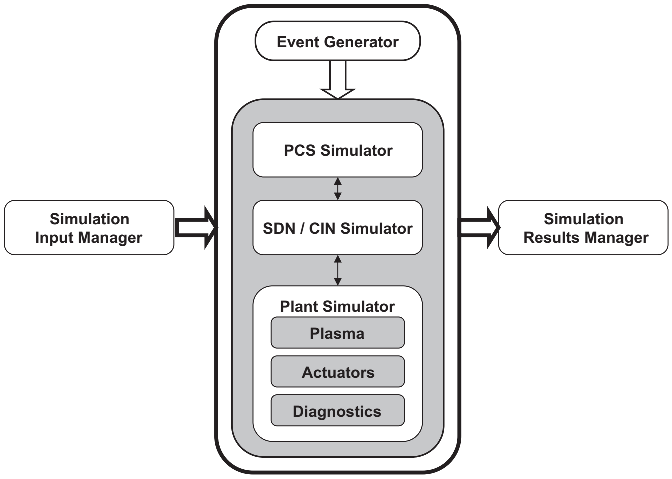

Fig. 1. The PCSSP environment combines various dedicated simulators.

preliminary architecture for the exception handling in PCS to be simulated (Section 4), and show how simulation runs shall be scheduled and logged (Section 5).

2. Plasma control system simulation platform (PCSSP)

PCSSP [3,10] will allow simulating Tokamak control behavior to help develop and test ITER PCS architecture, algorithms and code. It will combine:

- a plant simulator, which includes modules to simulate plasma, plant actuators and diagnostics, and the interlock system,
- a PCS simulator, which includes modules for simulation of pulse continuous control, and exception handling logic to be developed,
- an SDN and CIN simulator, which includes modules to simulate characteristics of ITER networks SDN (synchronous data bus network, for real-time data exchange) and CIN (central interlock network, for communication among interlock systems), if relevant, and may connect to external codes for more sophisticated plasma simulation, if needed (Fig. 1).

In addition PCSSP will host an event generator function to provoke occurrence of events in various modules, to investigate how PCS would handle plasma state changes, component failures, etc.

The basic idea is that the event generator will trigger the plant simulator or network simulator modules to provide a specific set and sequence of off-normal plasma and plant and characteristics. These can be observed by the control modules in the PCS simulator, where events are detected, and where the required exception handling policies are scheduled. Upon termination of a simulation run the output can be analyzed.

In the MATLAB/Simulink environment chosen PCSSP provides the means to integrate the dedicated simulators, and manage parameter input and results output for the simulation runs.

3. Events and event generation (EG)

3.1. Definition of event and exception

Different "event" definitions exist in science and philosophy. In the context of the ITER PCS we define an event as any system change that may (!) require to modify a control method. Depending on the system state or, discharge goal the occurrence of an event may then actually trigger a control modification.

We define exception handling as the modification of a control method in response to an event.

As a simple example the failure of a magnetic pick-up is an event. Depending on the system state (e.g. redundant pick-up available; plasma state established) various exception handling methods can be specified:

- to simply replace the failed pick-up by a redundant sensor (if the plasma is established and a redundant sensor is available);
- or perform a complex soft landing control scheme (if the plasma is established, and no redundant sensor is available).

In this simple example, no exception handing would be performed while no plasma is established, e.g. during technical calibration shots without plasma.

3.2. Classes of events

The task of PCS "to maximize scientific use and assist in investment protection" does not immediately provide the list of events relevant for ITER PCS. However, based on the event definition, we can analyze existing plasma control systems, and derive situations where control methods must be adapted or modified [11]. Such situations can generally be bifurcation of nominal operation states (which requires to adapt the control method to the actual nominal state), or degradation when off-normal failure states develop (and must be managed with appropriate control action). Bifurcation and degradation relevant to PCS may occur in the domains of the

- plasma;
- PCS controllers;
- SDN (synchronous data bus network);
- actuator plant systems and actuators;
- diagnostics plant systems (including data evaluation tasks);
- CIS (central interlock system);
- CIN (central interlock network);
- or plant operation conditions.

Plasma events comprise bifurcation of the various plasma regimes with distinct behavior, including onset/termination of instabilities.

Controller events include degradation patterns such as failures of controller hardware, computation time-out, violation of control algorithm operation windows, or observation of excessive control errors.

Actuator events are degradation from hardware failures, trips, and saturation or self-protection.

Diagnostic degradation events comprise hardware failures, noise or impaired accuracy, diagnostic specific measurement artifacts, excess of the accessible observation range, or violation of the evaluation model window.

CIS (including CIN) state bifurcation includes the various alarms relevant to PCS (in particular where PCS shall respond with dedicated actions, to control disruptions or runaways).

SDN network events are degradation due to hardware failures, packet dropouts, or excessive latency.

Operation condition events can be degradation patterns where actual PCAs (pulse control allowables) are violated, or operation state bifurcation from operator intervention, or resource availability.

3.3. Reproduction of events

To simulate nominal evolution of a pulse we represent the system by dedicated modules to compute the nominal data. E.g. an (ideal) diagnostic model computes the transfer function from a given plasma state into the measured data provided by the (ideal) sensor.