APPROACHING THE FINAL DESIGN OF THE ITER CONTROL SYSTEM

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Abstract

The control system of ITER (CODAC) is subject to a final design review early 2014, with a second final design review covering high-level applications scheduled for 2015. The system architecture has been established and all of the plant systems required for first plasma have been identified. Interfaces are being detailed, which is a key activity to prepare for integration. A build to print design of the network infrastructure, covering the full site, is in place and installation is expected to start early in 2015. The common software deployed in the local plant systems as well as the central system, called CODAC Core System and based on EPICS, has reached maturity and provides most of the required functionality. It is currently used by 58 organizations throughout the world involved in the development of plant systems and ITER controls. The first plant systems are expected to arrive on site in 2015 starting a five-year integration phase to prepare for first plasma operation. In this paper, we report on the progress made on the ITER control system over the last two years and outline the plans and strategies allowing integration of the hundreds of plant systems procured in-kind from the seven ITER members.

INTRODUCTION

The ITER project aims to demonstrate the feasibility of commercial production of fusion energy and is an international project with seven members (China, Europe, India, Japan, Korea, Russia and USA). The ITER agreement defines all of the systems to be provided in-kind through so called procurement arrangements by the members. The central organization, ITER Organization or IO, located at the construction site in southern France is responsible for the specification, integration and operation of the ITER device. With this setup the main challenge for the project is to integrate all of the systems supplied by the various members.

The ITER control system is segregated in three vertical tiers; conventional control, machine protection [1] and nuclear and personal safety, and two horizontal layers; the central control system and the local plant control systems. In this paper we will concentrate on the conventional part. IO is responsible for supplying the central system, but also for the integration of the local plant control systems supplied by the members.

To mitigate risks during integration, a major effort has been invested to provide standards and guidelines in a comprehensive document suite called the Plant Control Design Handbook. The latest version, comprising 31 documents and more than one thousand pages, was issued in early 2013 and is publicly available at [2].

The control system framework, called CODAC Core System [3,4,5,6] which is deployed on both the local and central control systems, has been developed further. This framework, based on EPICS, is freely distributed to the members with two releases per year, the latest one being v4.1 released in July 2013. User support is provided through a helpdesk. A four day training course and workshop has been run every month or two and more than 100 developers from all ITER members have been trained.

As a further measure to mitigate the risks during integration, IO provides a set of hardware devices free of charge to all plant system developers. This hardware is called the Instrumentation and Controls (I&C) Integration Kit and it includes computer and network interfaces running the CODAC Core System. The kit provides the interface between the local and central systems. The hardware is returned to the ITER site with the delivery of the plant system.

Proof of concept has been established in a number of use cases: power monitoring on ITER construction site, flywheel generator control at Frascati Tokamak Upgrade, real-time plasma density control at KSTAR Tokamak, etc.

The architecture of ITER control system has been presented elsewhere [7]. In summary it is a classical distributed hierarchical system with three levels, described by a control breakdown structure (CBS), where central supervision is CTRL, subsystems supervision are CBS1 and local plant control systems are CBS2. Communication is implemented by five Ethernet based networks dedicated for different purposes such as high throughput streaming and low latency real time.

FIRST PLASMA

The first major milestone in the ITER project is the achievement of “first plasma”. In order to focus and prioritize the work we have identified the plant systems required for this. Figure 1 illustrates the first plasma configuration with 13 subsystems and 89 local plant control systems delivered through 54 procurement arrangements from all ITER members. This corresponds to roughly half of the planned final system.

The subsystems can be characterized in four different groups depending on control system functionality and architecture.

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The first group comprises building management systems of 22 buildings, utilities such as power distribution and supply of compressed air, gases, water etc. and radiation monitoring. The group is characterized by many, but relatively small and independent, geographically distributed PLC based local plant control systems.

The second group comprises the cryogenic plant, cooling water system and vacuum pumping. They are all large industrial control systems including many tightly coupled PLC's implementing process control and monitoring.

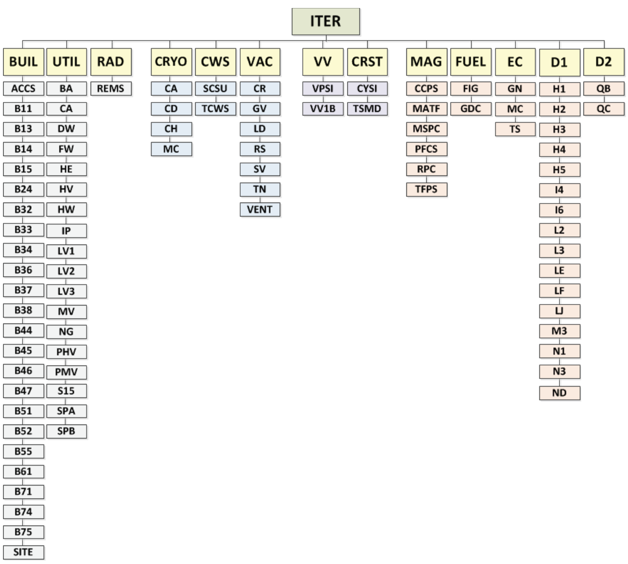

Figure 1: Control system architecture for first plasma.

The third group comprises the instrumentation of the large mechanical structures: the vacuum vessel, cryostat and thermal shield. The group is characterized by many sensors, but no actuators. Some of the sensors are sampled at a fast rate (kHz) requiring fast controllers and interfaces to the data archive network.

The fourth and last group is the most demanding from a control point of view. It comprises magnets and pulsed power supplies, fuelling, electron cyclotron additional plasma heating as well as diagnostics to measure the plasma parameters [8]. The latter are the sensors and the former the actuators for real-time plasma control. These systems need to interface to the real-time network as well as to the data archive network.

Although only the systems for the first plasma have been described here, the control system is designed for scalability and it will allow integration of the remaining systems after first plasma. These are first wall blankets, divertors, pellet injection, tritium plant, ion cyclotron additional heating, neutral beam additional heating, breeding test blankets and many more diagnostics.

INFRASTRUCTURE

The first part of the control system to be installed is the network infrastructure. This comes together with the construction of buildings and service trenches, the installation of cable trays and power distribution. A detailed design is being finalized providing connectivity to over 2000 local control cubicles (racks) in the various buildings. The architecture is based on a redundant dual star configuration, where the centres are located in the main control building and the personnel access building (PACB) which also houses the backup control room. The infrastructure consists of 24 active distribution points and patch panels in 14 buildings (Figure 2) and 200 passive network panels in rooms containing local control cubicles. The infrastructure supports five different CODAC networks, a dedicated interlock network and 3 safety networks, all implemented with single mode fibre optics. In addition hardwired copper links are used for magnet quench protection and nuclear safety. The installation of the infrastructure will commence in early 2015.

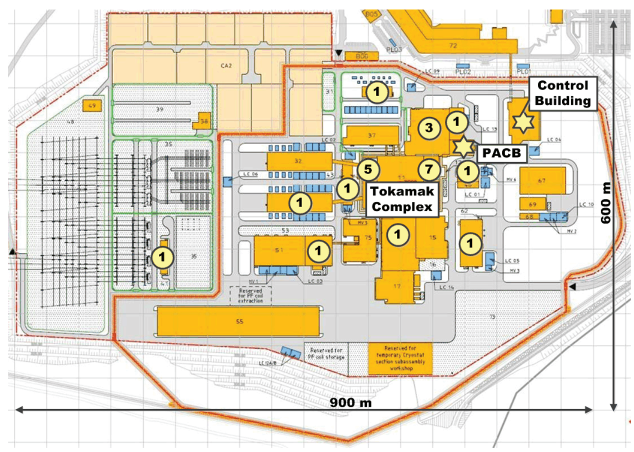

Figure 2: Geographic distribution of active network distribution points in different buildings on ITER site.

INTEGRATION

The sequence of activities for integration is as follows:

1) The building housing the local plant control system is declared "ready for equipment".
2) The network infrastructure is installed together with power distribution and the building is declared "ready for plant".
3) The plant system is installed together with the local control system.
4) Stand-alone tests and acceptance.
5) The local plant system is connected to the infrastructure.
6) The plant system is tested from the central system and accepted.

As the design of the various plant systems matures, the definition of the interfaces becomes more and more detailed. A major current activity is to define the details of the interfaces down to process variable level. This data is captured in a central database, called plant system profile database, which can be used for many purposes: report generation, provision of statistics, checking

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consistency and interfaces, generation of official interface sheets, and also as a starting point for the implementation of the actual local control system. This tool and process enforce the naming conventions, in particular uniqueness of process variable names. It also supports interface management by synchronizing the central database at IO and the distributed databases, which are part of CODAC Core System, located at the plant system developer's premises.

Work has started on detailed plans for integration. The unit of integration has been defined as a local plant control system (CBS2). A procurement arrangement normally delivers one or more local plant control systems. However, in some cases multiple procurement arrangements deliver one local plant control system, e.g. gyrotrons, vacuum vessel sectors and AC/DC converters. This is a consequence of the ITER agreement, where multiple member states want to obtain technical knowhow in a particular field. In these cases special solutions have to be found. This fact further complicates the integration, both at the plant system level and at the central system level.

HIGH LEVEL APPLICATIONS

A set of software applications running on the central servers allows coordinated and fully automated operation of the ITER device. Ideally one operator should be able to operate the whole plant from a single console. These applications comprise five major packages; scheduler, supervisor, plasma control, data handling and remote participation.

The scheduler is the tool kit, which allows the end user to prepare the experiment, e.g. plasma pulses, off-line by specifying all of the required parameters. The tool kit includes validation functions and interfaces to simulators as well as support for the workflow. It delivers the schedule to the schedule storage system.

The supervisor manages the standard states of all systems. It automates and coordinates by requesting state transitions and continuously monitors the states of the subsystems (CBS1) and local plant control systems (CBS2). It allows the ITER device to be configured by including and excluding subsystems and local plant control systems. The supervisor also fetches the schedule from the schedule storage system, executes sequences and downloads all parameters to all systems. It hands over to plasma control at the start of the plasma pulse.

Plasma control is fully in charge of ITER during the plasma pulse, which can last up to 3600 seconds. It is responsible for plasma initiation, wall conditioning, magnetic control (plasma shape, position, etc.), kinetic control (plasma density, fusion burn, etc.), disruption avoidance, disruption mitigation and event handling. It implements tens of distributed feedback control loops with sampling rates from Hz to kHz using the real-time network for communication.

Data handling is responsible for acquiring, transferring and archiving data over a high throughput network to a temporary storage. It is also responsible for streaming this data to a permanent storage and to provide tools to access the data. The initial aggregated data rate is 2 GB/s increasing to 50 GB/s in the final system configuration.

The support software for remote participation facilitates participation in operation from the ITER members. It includes the operation request gateway and methods to give access to data from the remote site. Remote participation is part of the ITER agreement.

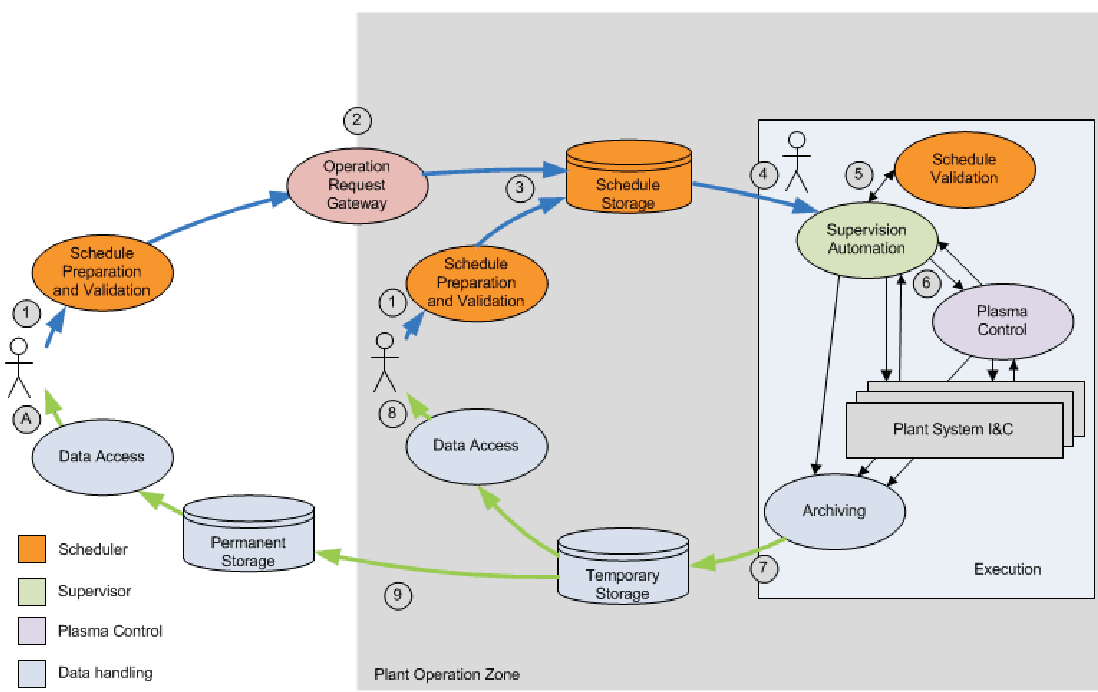

Figure 3: Main data flows during operation.

Figure 3 illustrates the main dataflow during operation. The schedule is prepared in advance either remotely or on site using the scheduler preparation and validation tools (1). If the schedule is prepared remotely it is transferred into the Plant Operation Zone (POZ) through the operation request gateway. POZ is separated logically and physically from the rest of ITER site and is located inside the nuclear fence. The schedules are stored in the schedule storage system (3). The operator requests the supervisor to fetch the schedule from the schedule storage (4). A final validation against the current plant conditions (5) is made before the parameters are downloaded to the local control systems and plasma control (6). The operator then initiates the plasma pulse and the supervisor sequences all local control systems using a standard state machine. Just before the start of the pulse the supervisor hands over control to plasma control, which is in charge throughout the pulse. The supervisor monitors the pulse and takes back control at the end. Data is continuously being produced and streamed to a temporary storage (7). Data from the temporary storage (8) can be accessed and processed during and after the execution. Data is streamed in parallel to the permanent storage outside the POZ where is can be accessed from remote sites (A). Figure 4 illustrates the supervisor sequencing and state machine, and Figure 5 illustrates the timing.

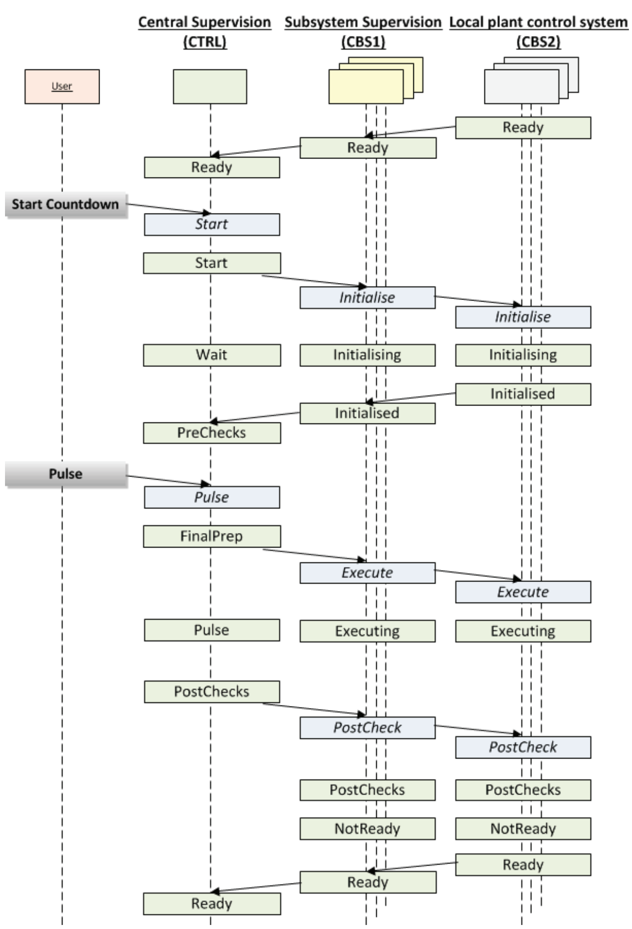

Figure 4: Sequence diagram of plasma pulse execution.

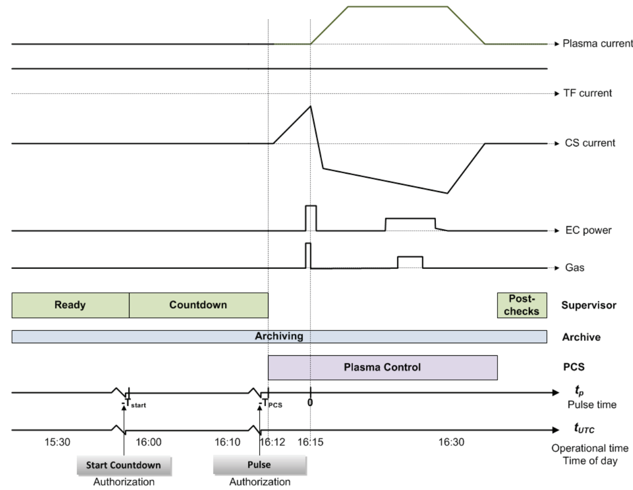

Figure 5: Timing of a plasma pulse.

CONCLUSIONS

The current status of the design of the ITER control system has been reported. The four main components for the mitigation of risks during integration, the Plant Control Design Handbook, CODAC Core System, I&C Integration Kit and training, are in place. The detailed design of the infrastructure is being finalized and installation will start early 2015. Integration of plant systems delivered by ITER member states will also start in 2015. Finally, the design of the high level software applications required for operation is progressing with a final design review scheduled for late 2015.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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