NEWS FROM ITER CONTROLS – A STATUS REPORT

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Abstract

Construction of ITER has started at the Cadarache site in southern France. The first buildings are taking shape and more than 60 % of the in-kind procurement has been committed by the seven ITER member states (China, Europe, India, Japan, Korea, Russia and United States). The design and manufacturing of the main components of the machine is now underway all over the world. Each of these components comes with a local control system, which must be integrated in the central control system. The control group at ITER has developed two products to facilitate this; the plant control design handbook (PCDH) and the control, data access and communication (CODAC) core system. PCDH is a document which prescribes the technologies and methods to be used in developing local control systems and sets the rules applicable to the in-kind procurements. CODAC core system is a software package, distributed to all in-kind procurement developers, which implements the PCDH and facilitates the compliance of the local control system. In parallel, the ITER control group is proceeding with the design of the central control system to allow fully integrated and automated operation of ITER. In this paper we report on the progress of the design and technology choices and we discuss justifications of those choices. We also report on the results of some pilot projects aimed at validating the design and technologies.

INTRODUCTION

The first concrete was poured in the ITER tokamak seismic pit in August 2011. Construction of the first two buildings is expected to be completed next year and the control building in 2015. In other words, the civil construction of ITER is in full swing. At the same time, more than 60 % of the value of in-kind procurements has been committed by the seven member states and design and construction of ITER components have started all over the world. These components of ITER, procured in-kind, come with their local control systems.

The main challenge for ITER control system is to integrate all these local control systems and enable integrated and automatic operation of the complete ITER facility. Since the ITER schedule is driven by specifications of in-kind procurements the priority of the ITER control group has been to establish the standards and technologies affecting the local control systems as well as facilitating future integration. Two evolving products have been developed to allow this: a set of documents, called the Plant Control Design Handbook (PCDH), defining the standards and a control system framework, called CODAC (Control, Data Access and Communication) Core System, implementing those standards and providing a development environment for local control systems. In parallel, the design of the central system is proceeding with the preliminary design review scheduled for late 2011.

Plant Control Design Handbook

The PCDH is a set of documents that defines mandatory rules, recommended guidelines, methodologies and catalogues of supported products. It is a living document with the latest release issued in February 2011. The PCDH specifies the design methodology for development of local control systems including deliverables. The product catalogue includes Siemens Simatic S7 PLC, IEI PICMG 1.3 PC, National Instrument multipurpose PXI6259 I/O board, Sarel cubicles and more.

The PCDH is contractually binding in all in-kind procurements, which include local control systems. It has been subjected to thorough review by representatives of all ITER member states. The ITER control group is actively promoting PCDH by organizing presentations and training in the member states as well as developing pilot cases for proof of concept. PCDH is available at [1].

CODAC Core System

CODAC Core System (CCS) is a control system framework that implements the standards defined in the PCDH and guarantees that the local control systems can be integrated into the central control system [2]. It runs on all computers within the ITER architecture, both locally and centrally. The most important feature is the use of EPICS [3], which guarantees communication using the channel access protocol. Major releases of CCS are made on a yearly basis. ITER contributions on top of EPICS are publicly available at [1].

Organizations contributing to the ITER project, in particular developers of local control systems can become registered users. A registered user is provided with support, such as software distribution, help desk and access to the development environment.

Before starting to discuss the chosen technologies and the reason for those choices, we briefly describe the overall architecture of the ITER control system. A more detailed description of the architecture is available in [4].

ARCHITECTURE

The architecture of the ITER control system is illustrated in Fig. 1. The main principles are maintained from the conceptual design [5], segregation in three vertical tiers; conventional control, interlock and safety and two horizontal layers; central and local. The local layer is procured in-kind, while the central layer is developed by the host, ITER Organization in France.

The current estimate is that there will be 220 local systems, grouped together and organized into 18 ITER subsystems. These local systems consist of a set of controllers, interfacing the actuators and sensors, and connected together via network switches to the plant operation network (PON). A similar architecture is applied for interlocks (CIN) and safety (CSN). Coordination and orchestration at the central level are first done at the subsystem level and then at the central supervision level. The human machine interface is provided by dedicated CODAC terminals located in the control room or close to the equipment for commissioning and troubleshooting purposes. For the safety system there is a dedicated safety desk in the main and backup control rooms.

In addition, a number of dedicated networks are used; TCN for time distribution and synchronization, SDN for real-time feedback and asynchronous events, ARCN for scientific data archiving and AVN for video transmission.

Table 1: ITER Controls Main Parameters

Parameter	**Value**
Total number of computers	1.000
Total number of signals (wires)	100.000
Total number of process variables	1.000.000
Total number of active operator screens	100
Update rate per screen (200 PVs)	5 Hz
Maximum sustained data flow on PON	50 MB/s
Total engineering archive rate	5 MB/s
Total scientific archive rate (initial)	1 GB/s
Total scientific archive rate (final)	20 GB/s
Total scientific archive capacity	Few PB/year
Accuracy of time synchronization	50 ns RMS
Number of nodes on SDN	100
Maximum latency asynchronous events	1 ms
Maximum latency sensor to actuator (SDN)	500 µs
Maximum jitter sensor to actuator (SDN)	50 µs
Maximum sustained data flow on SDN	25 MB/s

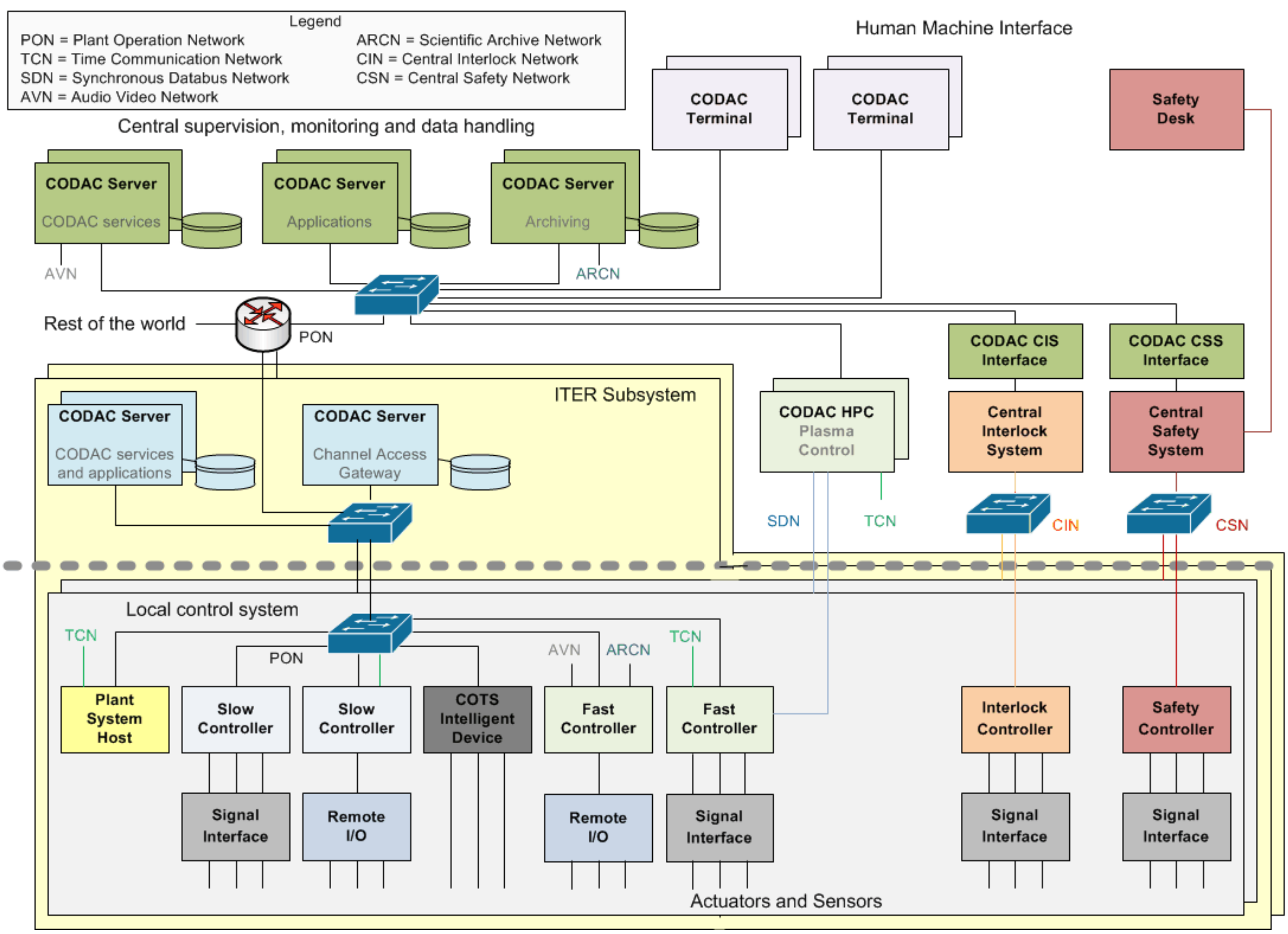

Figure 1: Physical architecture of ITER control system.

SELECTED TECHNOLOGIES

EPICS

A key technology decision was taken in 2009 with the adoption of the EPICS toolkit. This decision gave a head start to the development of CODAC Core System because all key requirements, such as robust communication and "live database", are solved by EPICS. In the preceding evaluation, open source solutions took preference over commercial ones because of longevity requirements. Of the open source alternatives EPICS was the clear winner because of its proven track record of reliability and scalability and the fact that it has been successfully deployed in almost all ITER member states, including on tokamaks in Korea (KSTAR) and the US (NSTX). CODAC Core System v2 comes with EPICS core v 3.14.12 and a selection of additional EPICS packages.

Linux

A second important decision was to adopt Linux as the base operating system. It is an obvious choice considering the selection of EPICS and the general market of large experimental facilities in the world. An evaluation was carried out of the three major commercial providers of Linux: Ubuntu, Red Hat and SUSE. Red Hat was selected for being the market leader and providing the longest support of major releases. CODAC Core System v2 comes with Red Hat Enterprise Linux (RHEL) v5.5 x86_64. It is planned to upgrade to v6.1 in the next major release due in early 2012.

It is estimated that more than 80 % of systems present in the entire control system are non-real-time or soft real-time. The remaining 20 % require real-time features not provided by RHEL. After an evaluation and benchmark of alternatives we have selected MRG-R from Red Hat.

Control System Studio

Control System Studio (CSS), developed by DESY, ORNL and Brookhaven, is an Eclipse-based collection of tools running on top of EPICS to monitor and operate large scale control systems. An evaluation was carried out to address both the functionality and performance of the product and match the requirements, mainly on the presentation layer, of CODAC. Many of these tools rely on a relational database (RDB), typically Oracle or MySQL. However, due to the uncertainty of MySQL's future as open source ITER has selected PostgreSQL as RDB. The evaluation therefore also included compatibility tests with PostgreSQL. The result was to adopt BOY (Best ever Operating interface Yet), BEAST (Best Ever Alarm System Toolkit), BEAUTY (Best Ever Archive UTility, Yet) and SNL Editor (State Notation Language Editor) in CODAC Core System.

Configuration

To address concerns related to the development of local control systems in all member states, an in-house development in unifying configurations has been undertaken. The basic idea is to capture configuration data like definition of process variables, input/output configuration, alarm definitions etc. in a relational database. These data are then used to auto-generate configuration files such as EPICS db files, BEAST and BEAUTY configuration files, BOY engineering screens, driver configurations etc. Further details of this project, called self-description data and using Hibernate, Spring and Eclipse technologies, are given in [6].

Development Environment and Distribution

The distributed nature of the ITER control system development (Fig. 2) requires high quality, both on the product (CODAC Core System) and the software distribution. To achieve quality and be cost effective unifying processes and technologies are essential. Major investments have been made in this area. Subversion has been selected as the version control tool, Apache Maven as the build tool, RPM (Red Hat package management) for packaging and for managing dependencies, Bugzilla as the issue tracking system, Jenkins for continuous integration and automated test execution and Red Hat Network Satellite Server for software distribution [7].

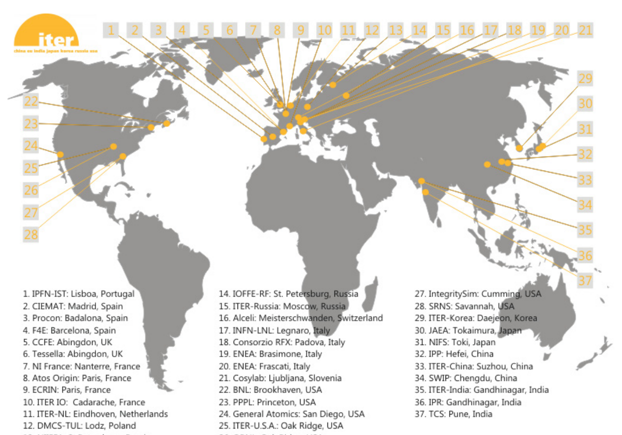

Figure 2: Registered organizations using CCS.

PTPv2 (IEEE 1588-2008)

The driving requirement for synchronizing ITER computers is the off-line correlation of different diagnostics data using absolute time stamps. The requirement has been set to 50 ns RMS. Requirements for pre-programmed triggers are much more relaxed (1 ms RMS). These requirements are matched closely by the precision time protocol (IEEE 1588-2008) now widely supported by many vendors. We have implemented the CODAC TCN network based on a PTPv2 using Meinberg and Symmetricom grand master clocks, IEEE 1588-2008 compatible industrial switches (Cisco IE3000 and Hirschman MAR1040) and NI PXI 6682 timing receivers as host nodes and confirmed the performance.

10 GbE Multicast UDP

The most important requirement for the real-time network SDN is to support control loops with a cycle times of 500 μs, which includes acquisition, computation, communication and actuation. Assuming a two hop configuration and that communication can use a maximum of 10 % of the available time budget yields an upper limit for latency between two nodes of 25 µs with a maximum jitter of 10 %. Such requirements are traditionally solved by reflective memory technologies. However, with the emergence of 10 Gb Ethernet, cut-through switches and wide support of multicast, switched Ethernet provides an alternative. We commissioned a benchmark with a major switch supplier confirming that switch latency for a cut-through switch is below 2 µs independent of package size. Using 10GbE NIC cards with protocol stack accelerators (Solarflare, Chelsio, Mellanox) we performed additional tests to measure latency including the UDP stack and the API. The results confirm that performance is comparable to reflective memory technology (Fig. 3). Considering technology evolution of Ethernet we have therefore selected 10GbE UDP multicast as our solution for the real-time network.

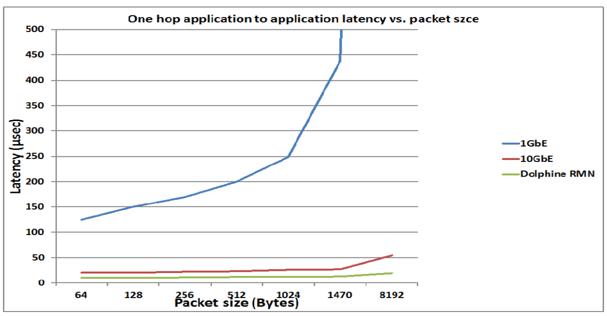

Figure 3. Measured latency 1GbE, 10GbE and RMN.

CURRENT R&D

The two biggest areas of technology selection not yet addressed are scientific archiving and plasma feedback control. A preliminary study of scientific data format has been carried out resulting in indications that HDF5 is the preferred option. This will be followed by the implementation of an archive prototype in 2012. Different options for high performance file systems are also being benchmarked, the main candidates being NFS4, HDFS and pNFS.

A major world-wide effort task with a consortium of experts in plasma control has been initiated. This task aims to detail the requirements and build engineering models of plasma control for ITER. In parallel an evaluation of existing real-time frameworks is underway. This framework, together with the real-time network, will make up the plasma control infrastructure. A primary candidate at this time is MARTe or some derivate of that.

A third area of active R&D concerns fast controllers, particular xTCA and FPGA technologies targeting diagnostics. A number of prototypes are being implemented with the aim of bringing such products into the PCDH catalogue of standard components.

PILOT PROJECTS

A number of pilot projects have been initiated to confirm the technology selections, prove the feasibility of implementing ITER controls using the selected approaches and identify any weak points to be addressed.

The ITER construction site and office buildings are currently powered by a 15kV substation. Applying the methodology and standard components defined in the PCDH, this substation has been successfully interfaced to ITER CODAC using two Siemens S7 PLCs, PSH, CODAC servers and CODAC Core System to monitor, archive and handle alarms for 400 process variables.

The neutral beam test bed facility in RFX Padova, Italy, will be used to test and commission the neutral beam injectors for ITER. The first system to be implemented will be an ion source and RFX has decided to apply CODAC Core System in this project. An initial evaluation has not shown any show-stoppers. The project is expected to be completed in 2015.

The Frascati Tokamak Upgrade (FSU) in Italy decided to upgrade the control for their flywheel generator using PCDH and CCS. This has been accomplished and an interface to the legacy control system has been implemented. Commissioning of the system during tokamak operation is planned in the autumn.

The control system of KSTAR (Korea Superconducting Tokamak Advanced Research) is based on EPICS and therefore a perfect candidate for testing ITER CODAC concepts. A collaboration project is underway to convert the hydrogen fuelling system to ITER standards and to implement closed-loop density control. The conclusion of the first phase is scheduled for late 2011 and of the second phase for late 2012.

CONCLUSIONS

The design and implementation of the ITER control system is progressing according to plan. Many technology decisions have been taken during the last year. The success or failure of the project will be determined by the acceptance of this work by the ITER member states responsible for providing in-kind local control systems.

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

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