DIAGNOSTIC USE CASE EXAMPLES FOR ITER PLANT INSTRUMENTATION AND CONTROL

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Abstract

ITER requires extensive diagnostics to meet the requirements for machine operation, protection, plasma control and physics studies. The realization of these systems is a considerable challenge, not only because of the harsh environment and the nuclear requirements but also with respect to plant system Instrumentation and Control (I&C). All the 45 diagnostics systems will require a large number of high performance fast controllers. The ITER Organization (IO) has published a set of documents to help the design of the I&C, called the Plant Control Design Handbook (PCDH) [1]. It defines mandatory rules for the system interconnect while providing guidelines and catalogues for the choice of the plant system I&C fast controllers. Most of the extremely complex ITER diagnostics systems are provided by the ITER Domestic Agencies (DAs) and their partners. On their demand the IO has created several diagnostics use case examples to enhance the understanding of diagnostics Plant System I&C and the associated deliverables. The use cases come complete with documentation and implementation, further helping the DAs, their suppliers and diagnostic responsible officers to meet the ITER diagnostics requirements. In this paper, we present the current status and achievements implementation and documentation for the ITER diagnostics use case examples.

PLANT I&C FOR DIAGNOSTICS

The data acquisition requirements for diagnostics measurement systems range from a few ADC channels sampled at 100 kS/s to more than 100 channels at 1 GS/s as in the case of microwave reflectometry. Visible cameras produce megapixel resolution images at frame rates up to 1000 fps resulting in data rates of the order of 2 GB/s per camera. Most of this data needs measurement updates every millisecond. The measured data needs to be sent for archiving and the real-time, preprocessed data to the plasma control system (PCS) within a fraction of a millisecond.

DIAGNOSTICS USE CASE EXAMPLES

The diagnostics use case examples have been developed for various reasons with the objective of simplification, cost reduction and standardisation and full integration with ITER control system (CODAC) [2-6]. The main reasons are:

- Produced on demand of DAs for plant system I&C documentation and implementation examples
- Provide incentives to follow the PCDH by simplifying work from design to commissioning, reducing the overall cost
- Verify that the I&C can be implemented following the PCDH standards

The diagnostic use case examples are not replacing the work of the domestic agencies to provide complete diagnostics systems with many plant specific functions. They rather allow the domestic agencies to focus on these plant specific functions and make use of the standard system functions and generic application functions. Other benefits are:

- The diagnostics use case examples provide a framework in which domestic agencies can immediately start deploying their applications
- Examples for basic functions of many plant systems.
- Demonstrate the usage of components from fast controller catalogue using supporting software.
- Documentation templates provided

The result of the diagnostic use case examples is set of clearly defined products, covering documentation, hardware solutions and software implementation which can be directly deployed in the plant system I&C development.

The documentation consists of:

- System Requirement Specification (SRS)
- System Design Specification (SDS)
- System Manufacturing Specification (SMS)
- System Test Plan/Reports (STP)
- System Operation / Maintenance Manual (OMM)
- Diagrams in DB based repository (Enterprise Architect)

The hardware and software consist of:

- Complete working example systems with the system and application functions (generic and specific examples)
- Hardware in fast controller catalogue
- Software support (Linux Driver and device support)
- Configuration data
- Plant I&C data in database
- Automation
- Network Interfaces (timing, archiving, real-time)

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SELECTION OF USE CASES

The selection of the diagnostics use cases has been derived from the needs of many diagnostics systems. It is based on frequently used hardware from the fast controller catalogue and the support of implementations in multiple form factors:

- Category of IO device (class of ADC/Camera)
- Hardware components and software functions cover many diagnostics.
- Coverage of high performance plant I&C in terms of data acquisition, (real-time) data processing, and data streaming for archiving.

The selected use cases are:

Diagnostics involved	IO type
Neutronics diagnostics	100-250 MHz ADC, 14-bit
Imaging diagnostics	Mpixel camera, 1000 fps
Microwave reflectometry Thomson scattering	1-2 GS/s 12-bit
Magnetic integrator	Sign. cond., 1 MS/s ADC

IMPLEMENTED FEATURES

The following features are implemented in the diagnostics use cases

- Health management
- Data/Image Acquisition
- Data Processing incl. Firmware applications
- Timing and synchronisation incl. time stamps
- Data Archiving services and network (DAN)
- Real-time services and network (SDN)
- Human machine interface (HMI)
- I&C data in the plant profile database (PSP)

USE CASE DOCUMENTATION

The work flow for plant I&C design documentation with its PCDH deliverables is shown in Figure 1. The designer starts with the description of the operational procedure of the relevant diagnostics. This is followed by a functional breakdown to level 2 for conceptual design and to level 4 (or more if needed) for the detailed design. The functions have to support all operational needs with process variables and their attributes being defined for individual functions as part of the detailed design. Then the hardware architecture is developed in which all of the functions can be implemented. The allocation of functions to hardware will be also documented. Finally a state machine for automation has to be defined, the cubicle layout with all cabling documentation developed, and the interface sheets are produced. All of these deliverables are documented in the design documents.

Systems Requirements Specification (SRS)

Almost all of the ITER diagnostics are procured according to functional specifications. Usually the requirements for plant I&C are not specified in sufficient details for the plant I&C designer. Therefore, the plant I&C system requirements needs to be elaborated in more detail, in the plant system I&C SRS.

The functional breakdown to level 2 represents the conceptual design. It decomposes the complex diagnostic function into smaller units as shown in the Figure 2.

Each function has to be described by its use cases, user requirements, system requirements, and interfaces with internal and external functions including user interfaces. All functions and their requirements have a unique and

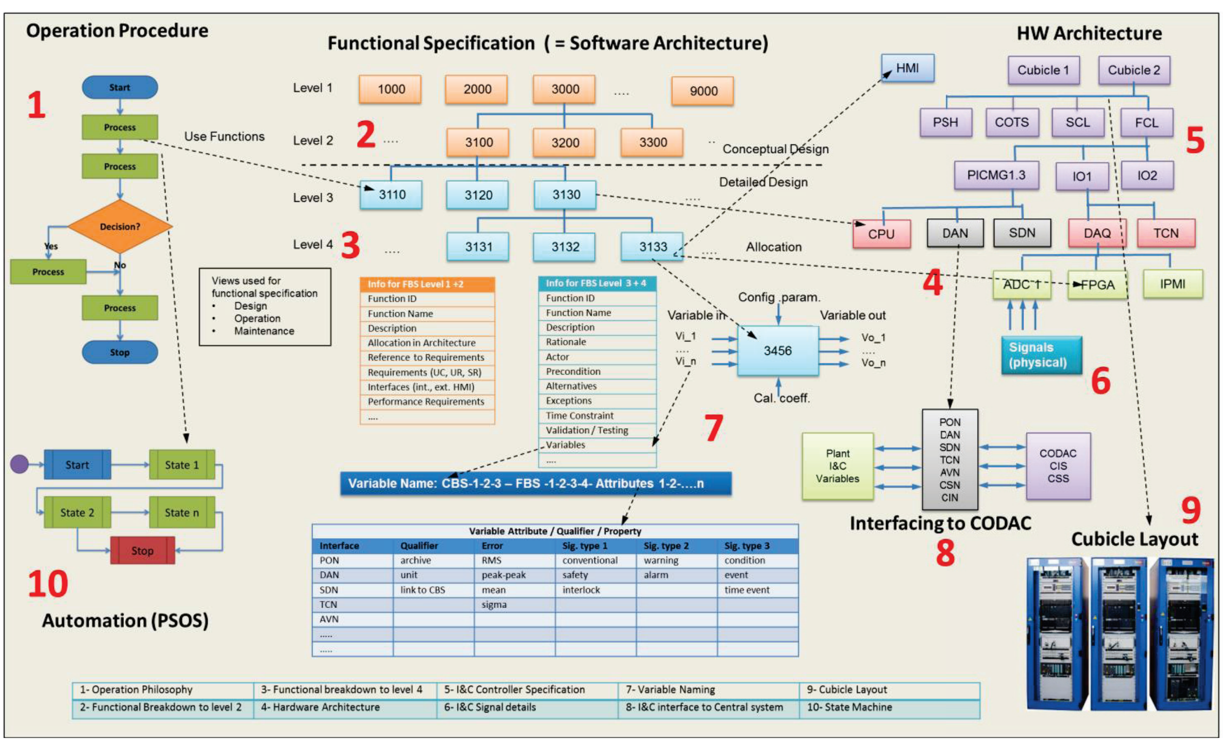

Figure 1: Documentation deliverables for I&C for design phase and as described in the PCDH. Illustrates also the workflow and the relation between the deliverables.

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structured ID which supports its use in the plant profile database.

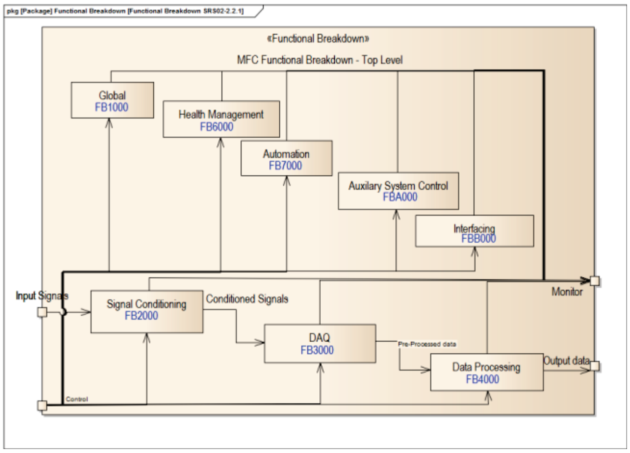

Figure 2: Functional Description at Level 1.

System Design Specification (SDS)

While the SRS provides a functional breakdown to level 2, the SDS elaborates on the details of the functions to at least level 4 (or more if necessary).

An example for the functional breakdown to level 4 is shown in Figure 3.

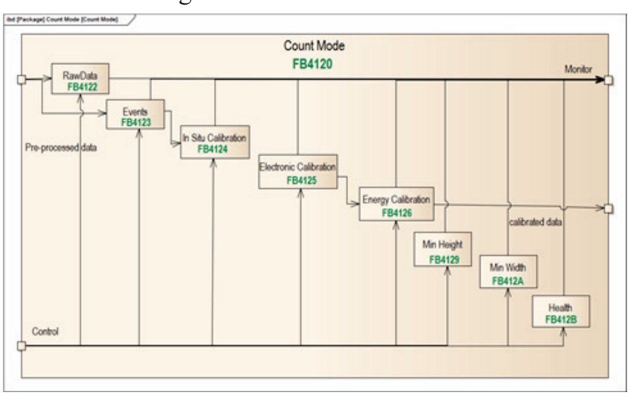

Figure 3: Example of functional breakdown at level 4.

Each function of the detailed design is described by its design rationale, process variables, interfaces including HMI, and functional validation.

Manufacturing Specification (SMS)

The SMS applies usually to several selected specific items of the system design. It is therefore not possible to cover all types of manufacturing specifications and provide a generic manufacturing template and example.

Acceptance Test Plan (STP)

The STP is required for factory Acceptance and Site Acceptance Tests (FAT and SAT). All functions are validated against the systems requirements using various scenarios required for plasma operation. During these tests, all interfaces to CODAC, Central Interlock System and Safety System are validated and their performance documented.

Acceptance Test Report (STR)

The results of acceptance testing are documented in the acceptance test reports. Problems are reported in an issue tracker tool and have to be resolved for final acceptance.

Operation/Maintenance Manual (OMM)

The OMM is an user guide describing the operational aspects for a diagnostic plant system. It provides an overview of the diagnostic system and describes the procedures required to prepare and execute plasma operation. This includes configuration, conditioning, calibration and troubleshooting procedures to ensure readiness for plasma pulse with the required performance and availability. Maintenance is also covered.

REPOSITORIES FOR PLANT I&C DATA

All I&C data is imported to the Plant System Profile (PSP) Database and is used to generate the interface sheets describing the information about variables exchanged between plant system and CODAC. The PSP database provides also interfaces to the ITER Engineering Database (EDB), the Self-Description-Data (SDD) framework, and other plant I&C development tools. The data is provided by the domestic agencies as part of the I&C deliverables.

USE CASE IMPLEMENTATION

Neutronics Diagnostics Use Case

The neutronics diagnostic use case example is based on fast controllers with multichannel ADCs in the 100-250 MS/s range. Both PXIe and MTCA.4 form factors are used. The use case can serve as a basis for the design of fission chambers, neutron flux monitor, and neutron activation system. Figure 4 presents an overview for the neutronics use case, in this example for fission chambers. An example for the human machine interface (HMI) is shown in Figure 5.

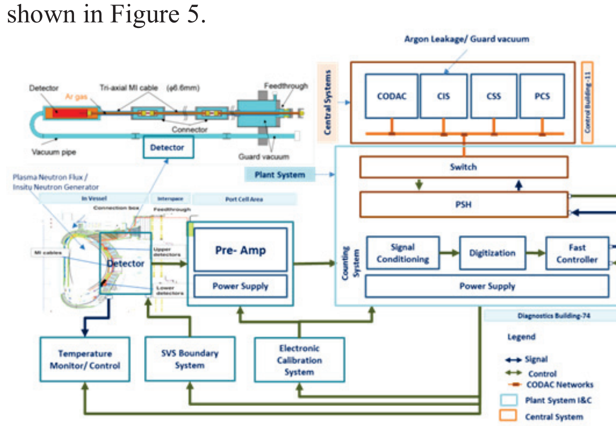

Figure 4: Neutronics use case architecture.

All basic features listed in a previous chapter have been implemented and tested. In the near future the following applications will be added:

- Data archiving
- Real-time network

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- Timing solution with time stamping

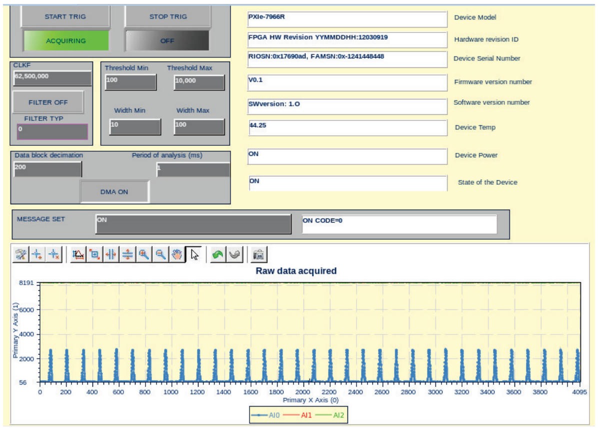

Figure 5: MFC application GUI.

Image Acquisition Use Case

The goal of the image acquisition use case is to develop a CODAC relevant prototype that can be used to assess the feasibility of I&C functions regarding to:

- diagnostics requirements (e.g. algorithmic performance)
- Plasma Control System requirements (e.g. computational performance)

Moreover, the developed parts (hardware and software) are reusable for many diagnostic systems (e.g. visible and infrared, spectroscopy, x-ray cameras, etc.).

The prototype is composed of a fast HD visible camera connected via a Camera Link interface to a frame grabber. As for the neutronics use case, fast controllers in PXIe and MTCA.4 form factor are used as shown in Figure 6.

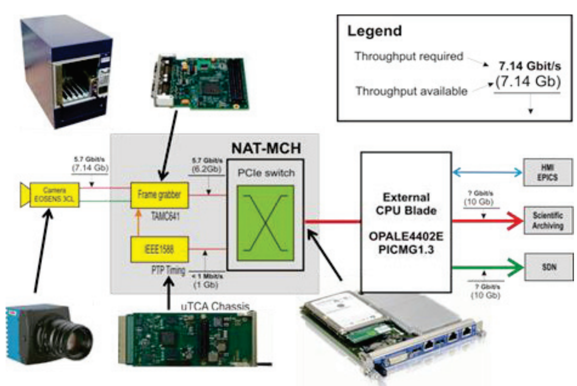

Figure 6: Hardware for image acquisition.

The use case allows collecting streams of images with a maximum resolution of one Mpix and frame rate up to 1000 fps. PCIe interface is used for image and control data transmission. A fast and low-latency image-processing is realized using Xilinx Virtex 5 FPGA device, whereas the external computer with GPU is dedicated for further image encoding and data buffering. An example for the operations display is shown in Figure 7.

The current software implementation supports all the basic features as described before. The IO is developing new modules for data formatting with time stamps and compression capabilities, data archiving and real time image processing.

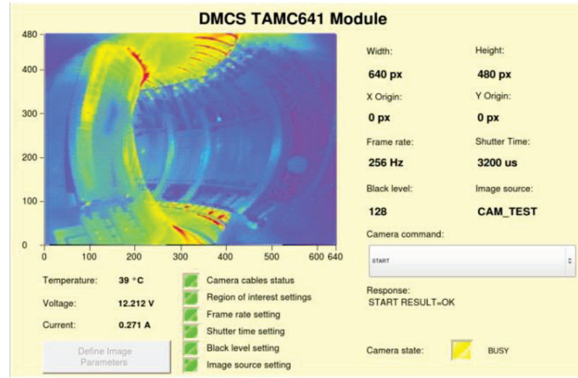

Figure 7: Operations display for image acquisition.

NEXT STEPS

The currently implemented diagnostic use case examples are still under development and testing. In the near term, the IO will add the high performance networks (DAN, SDN, TCN) to neutronics and imaging diagnostic use cases (both in PXIe and MTCA.4 form factor). In the following phase use cases for Thomson scattering / microwave reflectometry and magnetics integrators will be added.

CONCLUSIONS

For the development of the diagnostics use case implementations we have followed the engineering methodology described in the PCDH. The work covers all required plant I&C deliverables through all lifecycle phases from requirement capture to operation. The documentation templates and examples have shown to be particularly useful for design review preparation and are now widely accepted as a standard for diagnostic plant system I&C. The use case implementations are demonstrating fully integrated diagnostics plant system I&C. They can be rapidly deployed by the domestic agencies who can focus on creating plant specific functions. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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