Current status of SPIDER CODAS and its evolution towards the ITER compliant NBI CODAS

A. Luchetta, G. Manduchi, C. Taliercio

***Abstract*– The ITER Neutral Beam Test Facility currently under construction at Padova, Italy, consists of two experiments: SPIDER to test the ITER-size ion source with -100 kV acceleration potential, and MITICA to test the full ITER Neutral Beam Injector operating at -1 MV acceleration potential. While the former represents an intermediate step, also finalized to the ITER Diagnostic Neutral Beam, the latter will represent the final design and implementation of the full prototype of the ITER Heating Neutral Beams. Consequently, for the Control and Data Acquisition System (CODAS) of SPIDER there are no requirements for compliance with ITER CODAC, whereas the MITICA Heating Neutral Beam Plant System will comply with the ITER directives for CODAC management because that final system will be eventually integrated in ITER. SPIDER CODAS is currently under commissioning and the integration of the different frameworks that operate in an integrated way proved successful. The experience and solutions gained in SPIDER CODAS development will be reused as far as possible in MITICA and to provide at the same time the required CODAC compatibility, a set of ITER-like layers (networks) will be defined, using exactly the same protocol defined for ITER interfaces.**

Index Terms— Real-time system, Control systems, Distributed systems, Multicore systems

I. INTRODUCTION

THE ITER Neutral Beam Test Facility currently under construction in Padova, Italy, consists of two experiments: SPIDER to test the ITER size ion source with with -100 kV acceleration potential, and MITICA to develop and test the the full ITER Neutral Beam Injector (HNB) operating at -1 MV acceleration potential [1][2]. The former represents an intermediate step finalized to the development of the ITER full ion source and Diagnostic Neutral Beam; the latter consists in the development of a component that will eventually be cloned and installed at ITER. The two different experiments have different requirements for their Control and Data Acquisition System (CODAS). The MITICA HNB Plant System has to strictly adhere to ITER directives because the HNB will be eventually delivered as an ITER component[1]. No ITER directives are mandatory for SPIDER CODAS, letting freedom in its architectural definition.

Manuscript received June xx, 2016; revised xx xx xx.

The Authors are with Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), corso Stati Uniti, 4 – 35127 Padova, Italy (telephone: +39-049-8295039, e-mail: Gabriele.manduchi@igi.cnr.it).

[1] Actually, the NBI developed at Padova will not be physically delivered, but will provide the blueprint for the ITER NBI.

The following considerations have been taken into account when deciding the SPIDER CODAS architecture:

- The adoption of frameworks already used in fusion community is desirable because they provide ready solutions to commonly recurrent problems without the need of re-inventing solutions from scratch;
- Adhering to ITER directives also in SPIDER CODAS would however allow reusing developed solutions and systems also in MITICA CODAS. Otherwise, the development of MITICA CODAS must be started from scratch, despite the fact that it is going to control and supervise a system that is very similar (at least from the control and data acquisition point of view) to SPIDER.

However some design choices taken at ITER CODAC (COntrol Data Access Communication) and reflected in its directives were (i) different from the solutions adopted in many laboratories, including ours, or (ii) the adopted technology was not mature enough, or (iii) no indication was provided by ITER yet. The first situation refers to data management, and MDSplus, a data framework largely adopted in fusion community [3] has been preferred to the adoption of non-compatible HDF5 files in ITER[2].[4] The second case refers to the Time Communication Network (TCN). The IEEE 1588 protocol adopted in ITER is for sure a promising approach but, at the time SPIDER CODAS development started, the achievable time precision was not enough for a variety of high speed diagnostics [5]. Therefore a commercial solution, already well tested at RFX-mod, the other experiment running at Consorzio RFX, has been adopted for SPIDER CODAS. The third case refers to the choice of the software solution for real-time control. To date, ITER has not made a choice yet. Among the frameworks available in Fusion community, MARTe has been chosen in SPIDER CODAS for a variety of reasons that already led us to its adoption in the RFX experiment [6].
Other ITER directives have been instead followed in SPIDER CODAS such as the usage of the EPICS framework for slow control and supervision, and the Self Data Description (SDD) approach for defining in a unique description all the experiment configuration.
Using existing frameworks proved an effective solution that allowed fast development and reliable results, basically requiring only the implementation of the interface components for the integration of EPICS, MDSplus and MARTe into an organic system [7]. SPIDER CODAS is currently under

[2] The non compatibility derives from the fact that a modified version of HDF5 is used at ITER in order to support multi reader configuration, not provided by mainstream HDF5 distribution.

commissioning and will begin to operate the SPIDER experiment in late 2016.
In the rest of the paper, the gained experience in integration will be presented and the foreseen strategies for MITICA CODAS will be discussed.

II. Experience in System Integration

As stated before, the main effort in the development of SPIDER CODAS has been the integration of the used frameworks. In particular, EPICS has been integrated with MDSplus by developing two MDSplus aware EPICS components that are theMDSplus-based Channel Archiver for storing the values over time of the EPICS Process Variable (PV) values in MDSplus Pulse Files [8] and an EPICS Channel Access Server (CAS) to export configuration data stored in MDSplus as EPICS PVs. Storing all data handled in EPICS in MDSplus pulse files is the consequence of a major design choice in SPIDER CODAS that is the adoption of a unique repository for all data dealt with in the experiment. Consequently, the integration of the MARTe framework for real-time control consisted in “plumbing” the data flow from/to MARTe components to/from MDSplus. This has been achieved with the implementation of a MARTe component for streaming data produced in real-time by MARTe components into MDSplus pulse files, and another one for sending to MARTe components configuration data stored in pulse files [9]. A further MARTe component has been developed to export and import EPICS PV values in order to create a bridge between slow and fast controls.

The versatility of MDSplus pulse files, able to contain a wide range of data types in a hierarchical organization proved well suited to host both configuration data and experimental results. There is a strong relationship between ITER SDD and MDSplus pulse file. We decided in fact to adhere as strictly as possible to SDD approach proposed by ITER and made mandatory for ITER components. However SDD is more concerned in the structure of the CODAS system rather than on the data content. This limitation is compensated by a joint usage of MDSplus pulse files that will contain the data dealt with during the experiment. It is therefore necessary that the structure of the pulse files be consistent with what is defined in the SDD description. ITER miniCODAC provides an editor for SDD configuration and a set of tools for the generation of the configuration files for the specific components, such as the EPICS Databases for the definitions of the PVs. Some tools have been replaced in SPIDER CODAS, such as the configuration file for the EPICS archiver, and others added, such as the generation of the MDSplus pulse file template (Experiment Models) from the structure defined in SDD. This has been implemented by ad-hoc parsers accepting the XML files generated by the SDD editor.

In this way it has been possible to define all the experiment structure in a single point (SDD description) and all data in a single logical structure (MDSplus pulse file). This represents a step further in respect of the current ITER architecture defining two repositories for PV values and streamed data, respectively.

Our experience in the development of SPIDER CODAS confirmed once more the importance of reusing tested frameworks in place of starting a new implementation from scratch. EPICS, MDSplus and MARTe represent very good examples of frameworks relying on the experience gained in operation over many different applications. However, other considerations must also be taken into account when moving to the development of MITICA CODAS. The HNB developed in the test facility represents a superset of the HNB component that will be eventually installed at ITER. The purpose of the Neutral Beam Test Facility is indeed the study of many beam generation related aspects in order to solve many open problems for the realization of a 16.5 MW HNB using accelerated negative ions. While in ITER, the HNB will be a component involved in plasma heating, in the test facility the HNB is the experiment in itself. This explains why the number of involved diagnostics at the test facility will be much larger than what it will be in the delivered HNB component. From the CODAS point of view this means that only a small portion of the signals handled by the system in the test facility will be transmitted to ITER CODAC.

III. Evolution Towards ITER compliant HNB

The requirements and constraints in the MITICA CODAS differ significantly from those of SPIDER CODAS because of the added constraints derived by ITER directives.
Since the number of components and signals to be handled in MITICA CODAS during its operation in the test facility is much larger than in ITER operation, forcing the overhead due to ITER directives for all signals and components may represent an overkill. A possible solution is represented by an implementation of the communication buses defined in ITER for component interaction and defining a “border line” between internal HNB operation involving components that are specific to the test facility, and the signals that will eventually be exchanged with ITER CODAC. This border can be crossed only strictly adhering to the same directives ITER prescribes for its communication buses. In the following, the communication buses will be considered in more detail.

Plant Operation Network (PON)

ITER PON is designed to manage the information related to EPICS. The protocols adopted in PON are handled exclusively by EPICS and are transparent to final users who can rely on the location-independent availability of PV values. This network is already implemented in SPIDER CODAS that uses EPICS for supervision and slow control, and its porting to MITICA CODAS is straightforward. EPICS gateways will be likely required to partition the PV value update traffic distinguishing between PVs that are required by ITER CODAC to supervise the HNB operation and those handled internally in the HNB. This is however just a matter of configuration and does not affect the system architecture.
A special consideration must be done for the synchronization of the HNB State Machine with the ITER main State Machine. This synchronization is carried out by a protocol based on the

content of a selected asset of PVs. EPICS PVs are already used in SPIDER CODAS to keep components in step with the main SPIDER state machine, but the used protocol is different from the protocol used at ITER that was not defined yet at the time the state machine has been developed for SPIDER.

For this reason, the HNB state machine shall be re-implemented in order to adhere to the protocol specified by ITER. This will also require the development of a main state machine mimicking the ITER one during normal MITICA operation.

Data Archive Network (DAN)

Data archiving represents a system component for which completely different solutions have been adopted in SPIDER and ITER. The reason for the usage of MDSplus at SPIDER have been dictated by several reasons such as the ruggedness of MDSplus, the compatibility of stored data with a variety of languages and applications and the intrinsically distributed nature of stored information, letting easy data exchange with other laboratories. The use of MDSplus is foreseen also in MITICA, namely for those data that will be used only in the test facility and for the management of internal data. Of course MDSplus cannot be directly used for those signals that will be exchanged with ITER. In this case an interface fully compliant with that of DAN will be adopted. Using the DAN interface data will be sent along a stream component. The data source will act as a publisher, while the data archiver will be registered as a subscriber. It is worth noting that in this case the publisher is not aware of the method used to store data. In order to retain full compatibility with ITER DAN but use a unique storage strategy at the test facility a different version of the archiver will be developed, that will register as subscriber to the DAN streamers but will store streamed data in the same pulse files used for the rest of the system. As state before, the usage of the DAN interface is foreseen only for data to be exchanged with ITER CODAC, retaining direct usage of the MDSplus interface for the remaining signals.

Synchronous Data Network (SDN)

SDN will be used in ITER to exchange data in real-time applications for plasma and machine control. Its requirements are different from those of DAN because this network will be required to handle a much reduced amount of traffic data, but in this case strict requirements in communication latency are given. It is not yet clear to which extent the HNB will participate in the SDN traffic in ITER, but in any case such a component is foreseen in MITICA CODAS to be delivered at ITER. Even if it is likely that MARTe will be used internally for the management of time critical HNB operations, the final choice will depend also on the future choices of ITER regarding the real-time framework to be used in ITER. Whatever this choice is, the usage of SDN decouples internal real-time components with the ITER real-time framework. Integration of MARTe and SDN will be carried out by a new MARTe component for sending/receiving data to/from SDN. Another MARTe component for sending data to DAN will be developed in case any signal handled by MARTe has to be stored in ITER. While no buffering will likely be required for the SDN interface, due to the deterministic nature of SDN, an internal buffering mechanism will be required in the DAN interface in order to decouple real-time (MARTe) and non-real-time (DAN) behaviors. A similar approach has been taken in the MARTe – MDSplus interface in SPIDER.

Time Communication Network (TCN)

TCN will be used in ITER to communicate precise (absolute) time to subsystems. Precise time knowledge in all components is essential for the coordination of the system and for consistently tagging acquired data with time. The use of the IEEE 1588 Precise Time Protocol (PTP) over UDP and TCP is foreseen in ITER. PTP aware PXI devices will be used to generate pre-programmed triggers and phase locked clock signals required by the Analog to Digital (ADC) converters for a correct data acquisition. The TCN interface is extended also to software components that can be correctly synchronized thanks to the underlying synchronization of the CPU clock with a master, GPS-derived clock source. IEEE 1588 precision in time depends on the quality of the underlying network communication and as such it is expected that with fast networks it can reach a time precision less than 10 ns. The measurements carried out when SPIDER CODAS development started showed 100 ns precision that was not acceptable for a subset of high speed signals foreseen in some SPIDER diagnostics. For this reason a different approach has been taken in SPIDER CODAS, where commercial CPCI timing devices have been used [10]. These timing devices are connected via a fiber optic link carrying a base 10 MHz clock and coded asynchronous events. The usage of IEEE 1588 technology and therefore the integration of ITER TCN is foreseen in MITICA CODAS as the technology is now considered mature.

IV. Conclusions

The foreseen strategy for the integration of the HNB component in ITER CODAC still retaining the possibility of using well known components and systems in the test facility has been presented in the paper. It is worth stressing again the importance of an early and unambiguous definition of the interfaces (PON, DAN, SDN, TCN) that is even more important than having now a working implementation of such protocols. When a stable definition of the interfaces is available, the development of ITER components can proceed in parallel with the development of ITER CODAC.

Even if ITER miniCODAC is intended to be used to interface ITER components during Factory Acceptance Test (FAT), it is foreseen that in the HNB test facility some of the functions provided by miniCODAC will be also separately implemented. This holds in particular for the data exchange through DAN when the HNB will be running in the test facility so that the same data format can be used both for internal data not flowing through DAN and external data flowing through DAN. This approach does not preclude the usage of ITER miniCODAC in NBI FAT.

REFERENCES

[1] P. Sonato, P. Agostinetti, G. Anaclerio, V. Antoni, O. Barana, M. Bigi, *et al.*, "The ITER full size plasma source device design", *Fusion Engineering and Design*, vol. 84, no. 2–6, pp. 269-274, Jun. 2009

[2] V. Toigo, D. Boilson, T. Bonicelli, R. Piovan, M. Hanada, A. Luchetta, et al., "Progress in the realization of the PRIMA neutral beam test facility", Nuclear Fusion, 55 (2015), article number 083025.

[3] MDSplus. Available: http://www.mdsplus.org/.

[4] HDF5. Available: https://www.hdfgroup.org/HDF5/.

[5] A. Soppelsa, A. Luchetta, G. Nmanduchi "Assessment of Precise Time Protocol", *IEEE Trans. Nucl. Sci.*, Vol: 57, pp: 503-509, Apr 2010

[6] G. Manduchi, A. Luchetta, A. Soppelsa "The New Feedback Control System of RFX-mod Based on the MARTe Real-Time Framework", *IEEE Trans. Nucl. Sci.*, Vol 61, pp. 1216-1221, Jun. 2014

[7] A. Luchetta, G. Manduchi, C. Taliercio, "Fast control and data acquisition in the neutral beam test facility", *Fus. Eng. Des*. Vol 89, pp. 663-668, Jun. 2014

[8] G. Manduchi, A. Luichetta, C. Taliercio, "New EPICS Channel Archiver Based on MDSplus Data System", *IEEE Trans. Nucl. Sci.*, Vol 58, pp. 3158-3161 Dec. 2011

[9] G. Manduchi, A. Luchetta, C. Taliercio "Integration of Simulink, MARTe and MDSplus for rapid development of real-time applications", *Fus. Eng. Des.* Vol 97-97, pp 645-648, oct. 2015

[10] INCAA DIO4. Availabl;e: http://www.incaacomputers.com/component/resource/article/products/by-standard/36-pxi/52-dio4