THE CONTROL ARCHITECTURE OF LARGE SCIENTIFIC FACILITIES: ITER AND LHC LESSONS FOR IFMIF

Alvaro Marqueta, Juan Knaster, Koichi Nishiyama, IFMIF/EVEDA Project Team, Rokkasho, Japan
Angel Ibarra, CIEMAT, Madrid, Spain
Antonio Vergara-Fernandez, Anders Wallander, ITER Organization, St.Paul lez Durance, France
Markus Zerlauth, CERN, Geneva, Switzerland

Abstract

The development of an intense source of neutrons with the spectrum of deuterium-tritium (DT) fusion reactions is indispensable to qualify suitable materials for the blanket of the nuclear vessel in fusion power plants. An overlap of different layers will absorb the 14 MeV of fusion neutrons that will be converted to thermal energy and generate tritium to feed the DT reactions. IFMIF will reproduce those irradiation conditions with two parallel 40 MeV deuteron linacs, each at 125 mA continuous wave (CW) beam current, colliding on a 25 mm thick liquid Li screen flowing at 15 m/s. A neutron flux of 10^{18} $m^{-2}s^{-1}$ with a broad peak energy at 14 MeV will be generated in the forward direction through Li(d,xn) nuclear reactions irradiating 500 cm^3 volume capable to house around 1000 small specimens. An availability of the facility above 70% is expected to maximize the irradiation time. The design of the control architecture of a large scientific facility is dependent on the particularities of the processes in place or the volume of data generated; but it is also closely tied to project management issues. The LHC and ITER are two complex facilities with ~10^6 process variables and with different control systems strategies: from the modular approach of CODAC, to the more integrated implementation of CERNs Technical Network. This paper analyses both solutions, and extracts conclusions that shall be applied to the future control architecture of IFMIF.

IFMIF

A fusion relevant neutron source is a more than three decades long pending step for the successful development of fusion energy. In DEMO, like in future fusion power plants, the deuterium-tritium nuclear fusion reactions will generate neutron fluxes in the order of 10^{18} $m^{-2}s^{-1}$ with an energy of 14.1 MeV. Its blanket, a complex combination of layers of different materials aiming to maximize the conversion of neutrons into thermal energy and breeding tritium, will be exposed to intense degradation of materials due to the neutrons bombardment [1].

IFMIF, the International Fusion Materials Irradiation Facility, will generate a neutron flux with a broad peak at 14 MeV thanks to two parallel deuteron accelerators colliding on a liquid Li screen with a footprint of 200 mm x 50 mm. The energy of the beam (40 MeV) and the current of the parallel accelerators (2 x 125 mA) have been tuned to maximize the neutron flux and achieve irradiation conditions comparable to the plasma facing components of a fusion reactor [2] (see Fig. 1). IFMIF, with its 2 x 5 MW average power deuteron accelerators, will drive accelerators technology to unexplored regions.

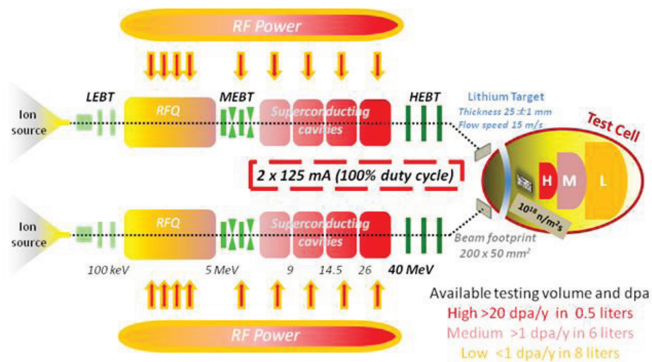

Figure 1: Schematic of IFMIF.

World fusion roadmaps demand not only the success of ITER to control DT reactions under magnetic confinement, but also available materials capable to withstand the unprecedented exposure to neutrons. Qualifying suitable materials at equivalent irradiation conditions as in a fusion reactor is an indispensable step that, concurrently with the understanding of the materials behaviour, will lead, in hand with computations techniques, to the development of new materials capable of making the operation of a nuclear fusion power plant viable. IFMIF, presently in its Engineering Validation and Engineering Design Activities (EVEDA) phase is overcoming its main technological challenges with the construction of prototypes of the accelerator, target and test facilities [3] and the preparation of an IFMIF Intermediate Engineering Design Report (IIEDR) [4]. Cost and schedule estimation, based on the experience gained with the prototypes construction, has been carefully prepared.

IFMIF is a large and complex scientific facility comparable to ITER or LHC; in particular regarding relevant parameters of its control system like I/O signals, number of variables or volume of data.

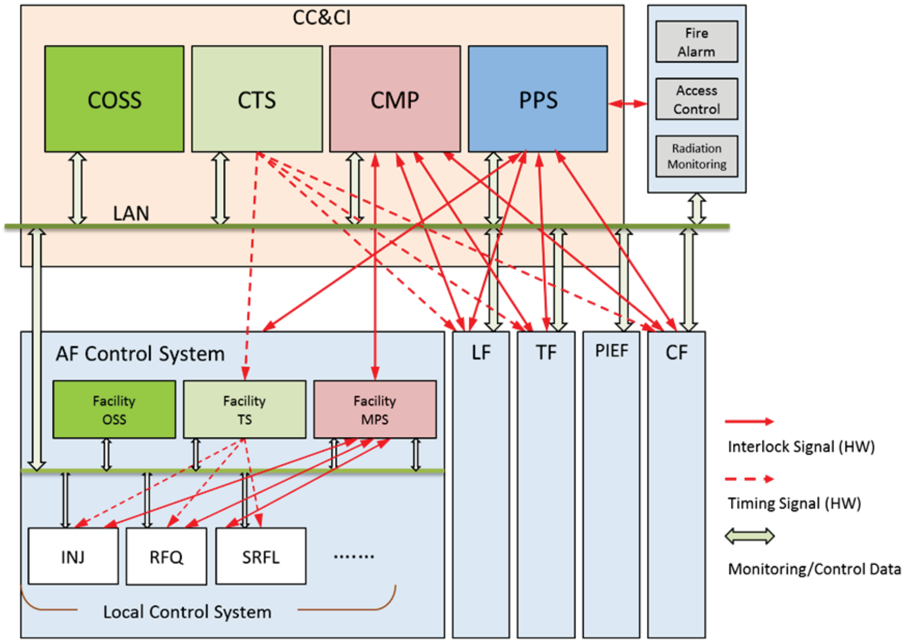

Figure 2: Overview of IFMIF Control System.

IFMIF CONTROL SYSTEM

IFMIF will be composed of five main independent facilities, though all intimately related:

- Accelerator Facility (AF), providing 10 MW and 40 MeV deuteron beam power in CW,
- Lithium target Facility (LF), to generate neutrons in a suitable flux and spectrum and evacuate the beam power
- Test Facility (TF), where test specimens are irradiated and includes remote handling hardware,
- Post Irradiation Experiment Facility (PIEF), where irradiated specimens are tested and
- Conventional Facility (CF), that includes the central control system and the management of the utilities.

All the facilities work together in a coordinated way through the different modes of global operation. However, each of these facilities shall be able to operate independently during commissioning phases. This drives the design of the control system of IFMIF [4].

Each of the facilities will require a local control system to be able to operate the associated sub-systems independently. There will also be a superior control layer in charge of supervision and management tasks (involving all different global/local operational states and issuing the necessary permit signals to the different facilities), as well as logging, alarming, etc. This system shall also centralize the tasks of machine protection, personnel protection and timing; and will include interface with the main utilities like fire alarm, access control and radiation monitoring systems.

Figure 2 shows the current schematic architecture of the central control systems of IFMIF, including the Central Operating and Supervisory System (COSS), the Central Timing System (CTS), Central Machine Protection (CPS) and Personnel Protection System (PPS). This superior structure will be replicated at the level of the local control system. This implies that while most of safety or protection logic will be executed at the upper layer, detection and/or execution responsibility shall be delegated to each local control system, closer to the process.

As a natural way to continue the efforts that are currently being put in place for the development of the Linear IFMIF Prototype Accelerator (LIPAc), presently under installation and commissioning in Rokkasho (Japan), the IFMIF control system will be based on the Experimental Physics and Industrial Control System (EPICS) [5]. It consists of a set of open source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific facilities such as particle accelerators, telescopes and other large scientific experiments. EPICS uses client/server and publish/subscribe techniques to communicate between the various computers. Servers (so called IOCs, standing for Input/Output Controllers) perform local control tasks and direct I/O interface, and publish this information to clients through the communication middleware Channel Access (CA). EPICS has become the first choice for the new main world scientific projects like ITER or the European Spallation Source (ESS) thanks to its scalability (with systems of up to hundreds of computers), proven reliability and ease of maintenance.

Given the previous requirements, the development team proposed to carry out a research through existing similar-sized facilities (already in operation, or still under construction), trying to identify common points and experiences that could be directly applied to the IFMIF control system design.

ISBN 978-3-95450-139-7

QUICK OVERVIEW OF LHC & ITER CONTROL SYSTEMS

LHC, the Most Powerful Collider

The Large Hadron Collider at CERN began its construction phase in the late 90s using the old tunnel which had previously hosted LEP. For the controls infrastructure, a brand new architecture was put in place to cope with the unprecedented complexity of the accelerator and its requirements. All layers of the control system were re-developed. New front-end software using a specific middleware to communicate with Java high level applications running in the control room; new timing system renewed at the hardware level; new databases put in place to describe the equipment, functional layout, configuration and management of operational data; and new industrial components such as PLC and SCADA selected for cryogenic and vacuum systems, as well as intensively used in the machine protection systems (beam dump, collimators, interlocks).

Two major changes where adopted during these new developments [6]:

- The consistent use of object oriented technologies for the control and beam-related systems,
- The wide use of industrial controls for the supervision of complete subsystems

These two new concepts have become with time a de facto standard in most of the experimental devices currently being developed.

The communication interface of these control systems is the Technical Network, restricted to equipment control, consisting of a highly sub netted TCP-IP routed network, based on a redundant Gigabit Ethernet backbone using fiber optical distribution.

Nevertheless, not all the controls infrastructure was brand new: the accelerator requires a chain of 'injectors' to operate, consisting of smaller accelerators for which older controls infrastructure had to coexist at a first stage with the one of the LHC. This fact imposed a number of restrictions at the time of the election of certain technologies, in order to assure proper compatibility.

ITER, the Largest Tokamak

The ITER project, still under construction in the south of France, will become the world's largest experimental tokamak, increasing by a factor of 10 the dimensions of the presently existing tokamaks.

The control system, together with the rest of the facility, is built from scratch, so no boundary conditions affect the design to start with. Nevertheless, one characteristic of this project is the procurement strategy in place, which implies a large dissemination of the development teams around the world; this has had significant implications in the final architecture, as will be described in what follows.

ITER control systems, named CODAC [8] (Control, Data Access and Communication), are separated in four main layers, from top-down: 1) presentation layer, 2) central control layer, 3) local control layer and 4) equipment layer. The two superior layers are linked by the multi-purpose, TCP-IP based Plant Operation Network, while the local control layer counts with a Plant System Network for each plant system. Other networks will be deployed for specific tasks (timing, real-time communications, video, etc.).

One of the most relevant components in this architecture is the Plant System Host (PSH). The PSH shall give the single point of entry to the plant system for the asynchronous communication. It acts as a gateway between the central CODAC systems and the local plant systems [7].

The first three layers will be covered by EPICS, selected as the software platform that will provide middleware services to equipment, and application services to users. Strong development efforts have been undertaken to improve and adapt the existing EPICS tools to the specific requirements of ITER, with special focus on the integration procedure of all the different local control systems into the Central Control system.

MODULAR VS INTEGRATED DESIGN

The global trends in development of new architectures are shared from small electronic gadgets to the largest control systems described previously. It consists in the specification of all the major components, the relationships or interfaces that exist between them, and the detailed definition of those interfaces.

Good designs shall minimize the coupling between components and maximize each component's internal cohesion. These designs are called modular and they promote the ability to develop, change, and refine individual pieces independently. This independence shortens development time and reduces the cost of supporting and maintaining the product. These qualities led to both object_oriented programming and the layered/modular design of communication networks. Modular architectures can involve design trade-offs to use adequate but not optimal standardized interfaces.

The opposite of modular architectures are integrated architectures. The hallmark of integrated architectures is close coupling between elements, efficiently synthesizing and consolidating functionality. Changes to one element can often require changes to others where there can be undocumented dependencies between elements. Although this makes such architectures more difficult to develop and maintain, it can allow them to achieve greater performance because all the components can be tuned towards that goal. Modular architectures sacrifice performance for flexibility. Product modularity leads to standardized interfaces and component specialization by different companies or development groups. Component interfaces become supplier interfaces.

Pure examples of integrated or modular architectures seldom exist in real products. But in today's large scale scientific control systems, with hundreds or even thousands of developers distributed worldwide, a purely integrated-like platform would be simply unmanageable.

ISBN 978-3-95450-139-7

A natural evaluation criterion of an architecture is how well the architecture allows the final solution to meet the needs of its users, while remaining flexible enough to cope with the likely-to-change requirements.

BALANCE OF THE INPUT REQUIREMENTS

There are many different types of inputs or constraints that define the final architecture of a control system. Besides the main tasks the control system has to accomplish and the performance required, there are circumstances that usually impose restrictions that will have to be taken into consideration for the final design.

First, there are the requirements of the future users, including the performance demanded, type of applications to be developed, volume of data and number of I/O signals to be managed, basic to correctly size the final system. The main sources or users (clients/servers) of data should be identified to avoid bottlenecks in networks or services. Availability requirements also tend to force the introduction of redundancies in the architecture, at the level of networks, whole systems or individual components. But there are also other factors that can affect certain decisions regarding the technology or the architectural model.

Certain technologies may be imposed, either by backwards compatibility with existing hardware or software platforms, greater availability, homogenization and ease of integration, or simply strategic/commercial decisions. For example, a particular brand of PLC or industrial PC could be selected for the whole facility, limiting the verticality that certain products can provide, or forcing certain providers to adapt to technologies unfamiliar to them. This process of standardization has been carried out at ITER and prevents and excessive variety of different hardware solutions, which would turn integration and later maintenance phases extremely complicated to handle [9]. When more freedom in the selection of components is allowed, interfaces between them should be simplified with the use of common protocols and gateways, so that backbone communications infrastructure remains unique.

The software solution/s selected for middleware, archiving, HMI, etc. will not only determine the type of hardware components to be used, but also the final architecture. In the case of commercial solutions, not always the system is open to work with components from different companies, especially in the PLC-HMI loop (unless open protocols are selected). For open software solutions like EPICS, either the hardware components are selected based on the catalogue of available drivers, or provisions have to be made to assure the required developments are achievable in time and budget.

Managerial issues also play an important role. A procurement strategy like the one adopted at ITER, where the ensemble is subdivided into Plant Systems (with the corresponding local control), each of which is developed independently from one another in different places of the world, and all have to be integrated into the central control system. In such case the approach of modularization, i.e., not only identify the interfaces but also standardize the development procedure as much as possible, becomes crucial. This scenario tends to impose a tree-like architecture, with a central system and several, hierarchically equivalent, sub-systems with a common interface.

Opposite to this, there are situations where the engineering teams are much closer to each other, for instance when most of the development is carried out within the same organization. Synergies are then easier to identify and adopt, and an optimization of the interfaces is possible by adapting the final solution to each particular case.

IFMIF, possibly next fusion world community big scientific project, will implement the lessons learnt in ITER; which in turn is settling a new approach of controls architecture driven by its international organization and the development of world communications networking; but cannot overlook its technological links with accelerators world.

CONCLUSIONS

With the aim of designing the best possible controls architecture for the future IFMIF experiment, different trends and two particular implementations have been analysed: ITER and the LHC. While ITER has focused the design of its control system on a modular solution, to ease as much as possible the future integration of the different developments coming from laboratories and companies from all around the world, the LHC could afford adapting the design of the architecture and certain components to more particular needs.

IFMIF will share with ITER an architecture based on EPICS driven by its likely common worldwide procurement strategy and modular design, but shall also integrate other solutions specific of accelerators technology implemented in the LHC.

REFERENCES

[1] M. Pérez et al., IFMIF: steps toward realization, SOFE 2013 San Francisco.
[2] J. Knaster et al. “Installation and Commissioning of the 1.1MW Deuteron Prototype Linac of IFMIF”, IPAC 2013, Shangai.
[3] J. Knaster et al., “IFMIF: overview of the validation activities”, Nucl. Fusion 53 (2013) 116001.
[4] IFMIF Integrated Project Team, “IFMIF Intermediate Engineering Design Report”, 2013.
[5] http://www.aps.anl.gov/epics/
[6] B.Frammery, “The LHC Control System”, ICALEPCS 2005, Geneva.
[7] A.Wallander et al., “Approaching Final Design of ITER Control System”, Proc. of ICALEPCS 2013, San Francisco.
[8] A.Wallander, “ITER Control System Architecture, Technical note”, 2009.
[9] F. Di Maio et al., “CODAC software distribution for the ITER plant systems”, Proc. of ICALEPCS 20011, Grenoble.

ISBN 978-3-95450-139-7