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IFMIF EVEDA RFQ LOCAL CONTROL SYSTEM INTEGRATION INTO MAIN CONTROL SYSTEM

M. Montis, L. Antoniazzi, A. Baldo, M. Giacchini, INFN-LNL, Legnaro, Italy
A. Jokenin, F4E, Barcelona, Spain
A. Marqueta, IFMIF-EVEDA, Rokkasho, Japan

Abstract

The RFQ apparatus Local Control System built for IFMIF EVEDA Project[1] has been designed and realized for being both a standalone architecture and part of a more complex control system composed by different sub-systems. This approach lets RFQ's engineers and scientists have a degree of freedom during power tests in Legnaro and during the RFQ integration in IFMIF-EVEDA facility in Rokkasho. In this paper we will describe the different aspects observed when the LCS was converted from the standalone configuration to the final integrated one.

INTRODUCTION

The required acceleration in continuous wave (CW) of 125 mA of deuterons up to 5 MeV poses IFMIF RFQ at the forefront frontier of high intensity injectors[2].

This RFQ is indeed meant to be the injector of a 5 MW deuteron linac (40 MeV final energy) for fusion material irradiation tests. The International Fusion Materials Irradiation Facility project aims at producing an intense (about $10^{17}s^{-1}$) neutron source facility, with spectrum up to about 14 MeV, in order to test the materials to be employed in the future fusion reactors.

The IFMIF-EVEDA project was funded at the time of the approval of ITER construction (2007); the task is to validate the IFMIF design by the realization of a number of prototypes, including a high-intensity CW deuteron accelerator (called LIPAc, Linear IFMIF Prototype Accelerator) for a beam power exceeding 1 MW. LIPAc is being installed at the QST site in Rokkasho (Japan). Accelerating structures of the prototype linac, operating at 175 MHz, are the RFQ and the first Half Wave Resonator cryomodule. LIPAc realization is a strict collaboration between Japan and Europe.

Technically the RFQ cavity is divided into three structures, named super-modules. Each super-module is divided into 6 modules for a total of 18modules for the overall structure. Before the construction of the entire RFQ prototype, the final three modules had to be tested at high power to verify and validate the most critical RF components of RFQ cavity and, on the other hand, to test performances of the main ancillaries that will be used for the IFMIF-EVEDA project (vacuum manifold system, tuning system and control system). The choice of the last three modules is due to the fact that they will operate in the most demanding conditions in terms of power density (100 kW/m) and surface electric field(1.8*Ekp). After the power test performed at Legnaro National Laboratories [3] and using the results obtained from it, the RFQ design (including the control system) has been finalized and prepared for the final installation in Japan.

GENERAL ASSUMPTION FOR THE CONTROL SYSTEM DESIGN

The RFQ Local Control System (LCS) Architecture approved by the IFMIF-EVEDA Collaboration is designed to optimize reliability, robustness, availability, safety and performance minimizing all the costs related to it (purchase and maintenance). Following this philosophy and the IFMIF-EVEDA Guidelines, it has been realized a control system network composed by two different kinds of hosts:

- Physical machines for critical control system tasks.
- Virtual hosts in machines where no particular functional task or hardware is required.

The architecture realizes the 3-layer structure described in the Guidelines and each layer defines a proper hosts group: equipment directly connected to the apparatus, control devices, Human-Machine Interface.

The Experimental Physics and Industrial Control System (EPICS) environment [4] has been chosen as framework standard for realizing the distributed control system required in facilities such as the one in construction in IFMIF-EVEDA project: the framework will be used to monitor and supervise any equipment composed the low level layer in the control system architecture, implement the algorithmic and provide to the higher layer (client services and operator interfaces) the information required to operate with the apparatus.

Because of the different conditions required by the power test and the final installation, the RFQ control system architecture has been designed to work as standalone environment and as part of the LIPAc control system environment. In addition, because of the RFQ power test executed in Italy was also a test bench for the entire control system, different solutions and changes in the architecture have been realized based on the results obtained.

Technical Assumption during Design Stage

The RFQ system is complex apparatus composed by several subsystems (radio frequency, vacuum, water cooling, etc.) developed using different hardware solutions. As consequence, every part of this structure must be properly integrated to obtain the desired degree of control.

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Following this criteria, the system has been designed using these assumptions:

- PLC hardware is chosen in tasks where security is the most critical feature.
- VME system is used where the acquisition speed rate is crucial.
- Common hardware (such as embedded systems) or virtual host (when possible)have been chosen when only integration is required.

THE RFQ LOCAL CONTROL SYSTEM – STAND ALONE CONFIGURATION FOR POWER TEST

As previously mentioned, the RFQ control system architecture has been designed to work as standalone environment and as part of the LIPAc control system environment. These two configurations are different in terms of purpose: while in the final installation hosts and devices are part of a more extended control network where high level services are provided by the Central Control System (CCS), in the power test configuration all the network control system services (such as archiving system, alarms, etc.) must be provided by the RFQ control system itself.

The architecture designed and realized for the power test is shown in Figure 1, where it is possible to observe the 3-layer structure mentioned before.

The LCS could be resumed by the following functionalities:

- RF signal generator;
- Fast acquisition system for the RFQ cavity power;
- Surface Temperature Monitor (STM) system;
- Bunch length monitor system;
- Vacuum system;
- Cooling system;
- Machine Protection System (MPS)
- Personal Protection System (PPS)

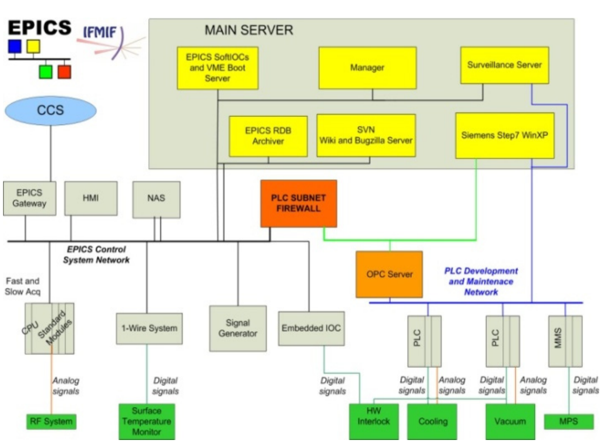

Figure 1: RFQ LCS architecture.

The fast acquisition is based on VxWorks real time OS which run over a VME architecture. The most important signals about RF power are sampled with a maximum rate of 1MEvents/s. To perform the automatic calibration of the acquisition channels, a useful tool based on EPICS was developed. Vacuum, Cooling, MPS and PPS functionalities are realized by SIEMENS® PLCs; in particular the PPS, for area access management and the slowest part of MPS, are in charge of a SIEMENS® Modular Safety System (MSS) which is SIL3compliant.Integration between PLC and EPICS environments has been performed through a dedicated Input/Output Controller (IOC) OPC Server and, to preserve PLC sub-system security, a firewall has been interposed between the OPC Server and the main EPICS network.

In Table 1 it is possible to analyse the principal parameters useful to understand the size of the installation.

Table 1: Control System for the Power Test: Details

Object	Numbers
IOCs	6
Databases	17
Process Variables (PVs)	1153
PVs archived	970
Control Panels	17

In this configuration the RFQ power test has been performed with good results: according to the test requirements, the experiment was considered successfully closed in February 27th 2015, after continuous operation at nominal voltage for more than4 hours (Fig. 2).

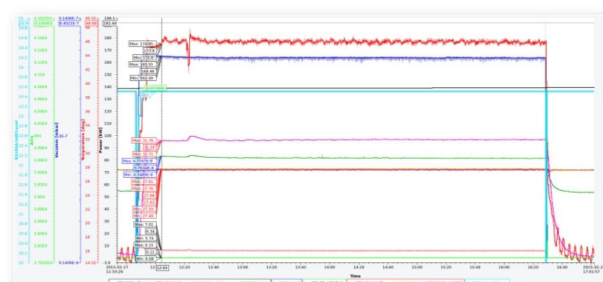

Figure 2: Result achieved during the RFQ power test with the control system in standalone configuration. Data is provided by the EPICS Archiver.

THE RFQ LOCAL CONTROL SYSTEM – CONFIGURATION FOR THE FINAL STAGE

According to the experience gained, different aspects have been taken in account during the migration from the architecture realized for the power test and the final control system:

- Explosion of PVs managed due to the fact the power test was performed only using a subset of modules composing the RFQ. As consequence an increment of the complexity at software and network layers has been taken in account.

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- Cubicle redesign for the final installation.
- Hardware-side interface installation (MPS, PPS and other LCS).
- Network and software migration and integration procedure required to reach the final stage.

In order to optimize costs and time for the final installation in Rokkasho, different operations has been performed; in addition different solution has been adopted in the RFQ LCS architecture in order to improve efficiency and maintenance.

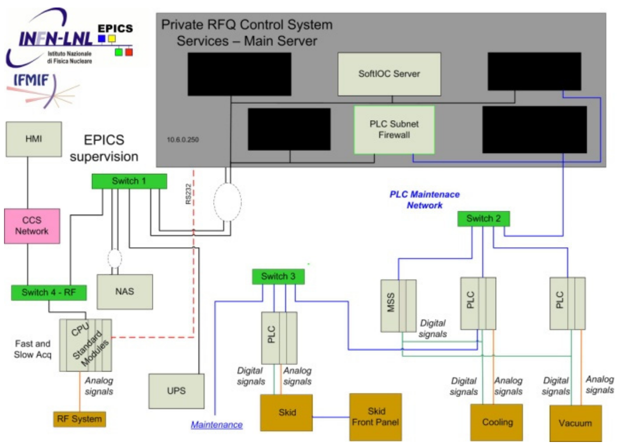

Figure 3: RFQ LCS Architecture for the final stage.

Local Control System – Final Design

The RFQ power test performed gave us the opportunity to verify the LCS in order to find weak points and provide alternatives accordingly to the directives imposed by the project.

One of the most critical aspect observed has been the PLC system integration into the main EPICS environment: the solution based on OPC Server was inefficient due to the limitation in term of PVs managed and freezing behaviours during our tests[5]; this aspect has been observed also during the injector installation stage in Rokkasho. As consequence we proposed and obtained by the project collaboration the migration from this approach to a new one based on the usage of the EPICS s7plc direct driver[6]: this new solution resolved the issues met and, at the same time, reduce the architecture's hardware complexity due to the fact the communication between EPICS and PLC system can be executed in a general software IOC (*softIOC*) running on a virtual machine. On the other hand, through this solution data update and synchronization in case of network failure is not well managed: at LNL we defined a state machine based method to verify data integrity [7].

Trying to further simplify the LCS architecture, it has been decided to substitute the PLC firewall hardware with a virtualized host which performs the same task: a virtual machine equipped with Endian Firewall has been installed and configured in order to have the EPICS IOC Server virtual machine as the only host enabled to communicate into the PLC sub-network.

From the final RFQ LCS architecture realized (Fig. 3), it is possible to observe the presence of several virtual machines hosted in the main server hypervisor: these machines represent the set of services used during the power tests at LNL that won't be used at regime (after the integration).In order to optimize the integration stage and let us an additional degree of freedom, we decided to leave the virtual hosts available in the hypervisor and use them during the migration stage: this approach let us to perform different tasks and operation in parallel.

LCS Hardware Implementation and Preliminary Electrical Tests at LNL

Due to the different configuration required for the power test and the final stage, LCS hardware has been recabled and extended in size (because of the increasing number of devices and sensors required for the entire RFQ apparatus): cubicles have been reassembled to perform preliminary electrical checks before the shipment.

In the implementation stage, different solutions have been adopted to minimize installation time and optimize maintenance:

- The adoption of Junction Boxes placed along the RFQ apparatus used to centralize wired connections (visible in Fig. 4).
- The usage of connectorized cables for all the linkage among the different LCS parts (cubicles, junction boxes and terminal devices).
- The installation of a Uninterruptible Power Supply (UPS) inside the cubicles let the LCS be partially ready before the final electrical installation in Japan.

An important part of the checkout test performed before the shipment was executed to verify the congruency between the diagrams and the hardware, the correct design and execution of the cabling according to electrical standards and regulations.

Figure 4: RFQ LCS junction boxes (on the left) and cubicles (on the right).

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During this phase, all the cables (included the once between junction boxes and final devices) were tested and checked for electrical continuity, lengths and labelling. At final verification stage, all the LCS apparatus were connected and powered to verify the correspondence of about 500 I/O connections (PLC inputs and outputs). Only few minor adjustments were necessary to correct the hardware and the electrical schemes.

At the end of the test a certificate of compliance was released by an external contractor for the cubicles, while junction boxes were already certified by the producer.

RFQ LCS INTEGRATION

Basically the RFQ LCS integration is made up of two main tasks:

- Hardware integration, composed by the hardware installation (device, cubicles and ancillaries) and the connection to the different sub-systems composing the accelerator (injector LCS, low level RF LCS, MPS, PPS, etc.).
- Software integration, composed by the reconfiguration of all the hosts forming the RFQ LCS from both the network point of view and control system services (NFS, archiver, alarm, etc.).

These two aspects have to be performed in parallel but, because of several preliminary steps required to operate with the RFQ apparatus and the IFMIF-EVEDA project schedule among the different subsystems involved, the RFQ LCS installation and integration has been made in different stages and following different configurations:

- For the RFQ baking operation, a partially integration is required in order to operate only with the vacuum subsystem. In this configuration the Human Machine Interface (HMI) machine must be already available; in addition the archiver service is required.
- For the RFQ conditioning, cooling and RF acquisition subsystems must be installed and the LCS must be integrated with the MPS, PPS and the different LCSs involved in this step.
- For the final operational setup, the entire LCS will be fully integrated in the CSS.

While the hardware installation is a quite straight procedure (different subsystems are required in different stages), the software integration has required a different approach: formally the network migration requires a permanent modification on the LCS topology in function of services and permissions. Because of the requirement in the different stages of the installation, it has been decided to adopt:

- A hybrid solution during the RFQ baking operation, where the LCS works as a standalone network using the final CCS IP. Particular attention has been done in order to avoid network bridges between the two systems. In this stage every single host has been configured with the final IP and the main services required has been provided by the LCS itself through the virtual machines realized and used during the RFQ power test at LNL. For the archiver system, dedicated engine configurations have been set and used for the baking operation. These configurations won't be used for the final stage.
- A fully integrated solution has been used for the RFQ conditioning and the final operational setup: because of the requirements of connectivity among the different LCSs and the CCS in order to operate with the machine, the EPICS software must be fully operative. As consequence all the network services must be ready and all the software must be fully integrated in the CCS architecture.

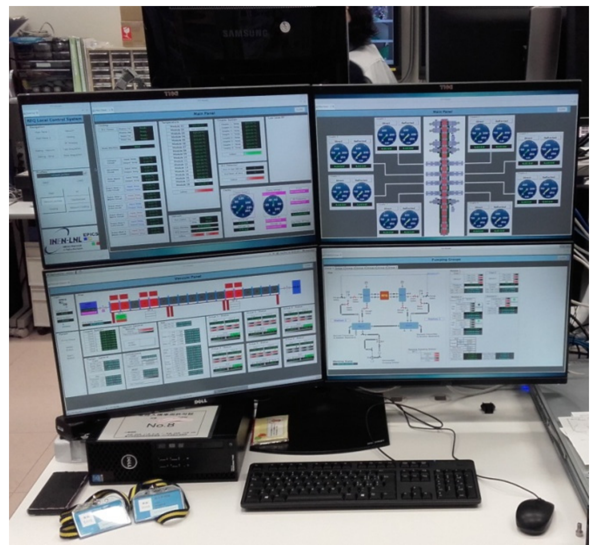

Figure 5: RFQ LCS Human Machine Interface installed in the control room.

Figure 6: RFQ apparatus and automatic RF calibration operation.

As previously mentioned, the integration process occurred before the conditioning operation required reconfiguration of all the machines (physical and virtual) connected to the LCS network, also in case of temporally solution such as the archiver system. Furthermore each machine and the relative EPICS communication was reconfigured ad hoc and fully integrated in order to be in accordance with the standards adopted by the IFMIF-EVEDA project and ready to finalize the final acceptance test required by the collaboration.

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In particular:

- Reconfiguration of principal information related to network service (hosts allowed and denied, IP, etc.), time service and EPICS environmental variables.
- For the PLC Firewall virtual machine, the LAN network part has been left unaltered and only connectivity tests have been executed.
- Reconfiguration of the VME boot parameters, including network, boot image and EPICS application source, which are provided by a dedicated server in the CCS.
- Reconfiguration of the HMI and RFQ IOCserver machines related to NFS service required by the CSS in order to mount the shared folder containing the EPICS environment and the RFQ EPICS applications.
- For the first part of the conditioning stage, the RFQ LCS archiver system has been left running in parallel to the one provided by the CCS. In this occasion further engine configurations have been performed in order to store the set of EPICS PVs used during the conditioning.
- Configuration of the EPICS software with the data information acquired during the installation process. In particular,the information related to the RF line calibration is necessary for execute calculation related to the principal RF parameters, such as power involved and field flatness. In order to optimize the time required for the calibration, an automatic tool based on EPICS framework has been used for the entire process (Fig. 6).
- Integration of EPICS PVs required for the data exchanged with other LCSs: PV names have been set into the software and minor configuration to the RFQ EPICS software was required in order to use the EPICS-PLC communication method defined by the LNL team and based on s7plc EPICS driver. In addition the information has been added to the RFQ control panel interface (Fig. 7).

Among the integration process, several minor bug fixes have been performed to the control system software (both EPICS and PLC side) in order to adjust eventual issues discovered during the integration.

The actual size of the RFQ LCS is visible in Table 2: considering the power test has involved only part of the entire RFQ, for the final installation the number of database decreased due to the simplification on the number of device control used (for example the surface temperature monitor has been removed in the final design).At the same time the number of databases and PVs increased due to the effect of the usage of the new communication method based on s7plc EPICS driver defined at LNL, which requires additional records for every single data exchanged between the two environments.

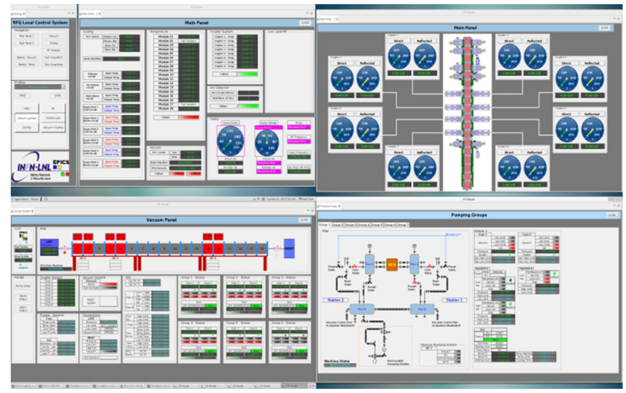

Figure 7: Control panels developed for the RFQ LCS.

The number of PVs archived is related is decreased because the archiver service has been used as part of the debug system during the RFQ power test and several data stores were related to control check purpose.

Table 2: Control System Comparison Between the Power Test and the Final Installation in Rokkasho

Object	Power Test	Final Stage
IOCs	6	4
Databases	17	25
Process Variables (PVs)	1153	8852
PVs archived	970	450
Control Panels	17	21

CONCLUSION

Technical solutions adopted during the design stage let us reduce time and effort during the installation and give us the degree of freedom of working as standalone system and as part of the entire IFMIF control system when required. Actually the system is fully integrated into the CCS and it is performing the first stage of the RFQ conditioning, and the results obtained by the formal acceptance tests and baking stage let us be confident in the good prosecution of the RFQ operations until the end of the commissioning.

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