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UPGRADE OF THE CONTROL SYSTEM FOR THE LHC HIGH LEVEL RF

Y. Brischetto, L. Arnaudon, V. Costa, D. C. Glenat, D. Landré, CERN, Geneva, Switzerland

Abstract

The acceleration of particles in CERN's Large Hadron Collider (LHC) is carried out by sixteen superconducting radiofrequency (RF) cavities. Their remote control is taken care of by a complex system which involves heterogeneous equipment and interfaces with a number of different subsystems, such as high voltage power converters, cryogenics, vacuum and access control interlocks. In view of the renovations of the CERN control system planned for the Long Shutdown 2 (LS2), the control software for the RF system recently underwent a complete bottom-up refactoring, in order to dispose of obsolete software and ensure the operation of the system in the long term. The upgraded software has been deployed one year before LS2, and allowed successful operation of the machine. This paper describes the strategy followed in order to commission the system and to guarantee LHC nominal operation after LS2.

INTRODUCTION

Any kind of software needs recurring updates, and the control software for accelerator equipment at CERN does not differ. Taking advantage of the downtime of the accelerators during the Long Shutdown 2 (which started in January 2019 and will last until end of December 2020), it was decided to perform a major update to FESA (Front-End Software Architecture) [1]. Most of the CERN control software applications rely on this framework, therefore they will have to be renovated before the end of LS2.

One year before the start of LS2, our team started the renovations of the software controlling the LHC 400 MHz RF system (ACS), which is based on FESA, and as a result we were able to validate the new software during one year of LHC operation.

OVERVIEW OF THE ACS RF SYSTEM

Sixteen superconducting radiofrequency cavities guarantee the acceleration of particles in LHC [2]. The 400 MHz cavities are installed in groups of four inside cryomodules, and two cryomodules are installed on each beam line. Each cavity is powered by a 300 kW klystron and shares a 58 kV voltage power converter and a high voltage equipment bunker with the other cavities installed in the same cryomodule.

From an RF point of view, each cavity is driven by one klystron amplification chain, thus the concept of *line* was defined to identify the full chain of devices controlling one specific klystron and the cavity connected to it. Moreover, since a group of four klystrons shares a common power converter and high-voltage equipment bunker, and drives the cavities installed inside one cryomodule, the concept of *module* was also introduced, to address the control of the power converter and of the HV equipment related to each cryomodule (as illustrated in Fig. 1). Each *line* and each *module* is controlled by one dedicated programmable logic controller (PLC), therefore the overall control system is composed of sixteen *line* PLCs and four *module* PLCs.

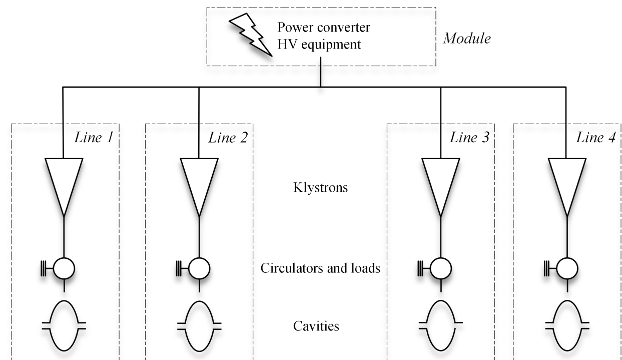

Figure 1: Logical view of one ACS module and four lines.

Along with them, one additional PLC is charged with the control of *services* as the fast interlock module for the beam dump and environmental sensors monitoring the LHC Faraday cages, which are installed underground and host some of the low level RF controls.

CONTROL BEFORE RENOVATIONS

The remote control of equipment is generally integrated into CERN's control system by using FESA, a CERN-made C++ framework that lets developers create control software in a common manner, regardless of the equipment to be controlled. Until some years ago, FESA allowed the integration of PLCs, offering developers the opportunity of only having to define communication interfaces, relieving them from the development of the code necessary to handle data transfer with the controllers.

The control software for the ACS RF system that was in use before the renovations presented in this paper was composed of six different FESA classes, three dedicated to the communication with the PLCs, and three others handling the exchange of status and control data between the lines, modules and the additional systems. High-level control interfaces were developed using standard tools offered by CERN's BE-CO (Controls group of the Beams department), whereas most of the expert interfaces were implemented through LabVIEW panels. The variety of the control software was obviously a limiting factor, which implied that users had to use different applications to control different parts of the system, something that could definitely be improved.

SOFTWARE UPGRADES

In light of this situation, along with the advent of the major update of the FESA framework, and important changes

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planned on the control interface of power converters, a complete rework of the control software of such a heterogeneous architecture as the ACS RF control system was then deemed necessary.

Communication with PLCs

Although the latest version of the FESA framework, FESA3, does not offer the integration of PLC communication, this same feature is nowadays offered by a new tool, SILECS (Software Infrastructure for Low-level Equipment Controllers), formerly known as IEPLC [3]. SILECS is a CERN-made software which decouples the setting up of the communication with controllers from the implementation of a FESA class, by generating a source file that, once uploaded to the controllers, makes the data flow possible without requiring any additional code. This is done via the definition of so-called SILECS *classes*, which represent the actual data that has to be exchanged with a controller.

In order to perpetuate the *modules-lines-services* paradigm, three SILECS classes were developed for the ACS system.

Control of ACS Modules

As previously discussed, the control interface of the power converters was planned to be drastically changed. According to the previous implementation, the main observable parameters for one specific device were transmitted in the form of a large array, thus the control software for the ACS modules contained code that performed the extraction of the parameters necessary to operate the RF. The new version of the interface presents the same data in the form of fields and grouped in properties, therefore the refactoring of the software controlling the ACS modules involved the complete rewriting of the code handling the readback of data from the power converters. Another section of the software interprets commands coming from the high level control interfaces, controls the RF system, communicating with the PLCs though SILECS, and in parallel, using RBAC (Role-Based Access Control) and RDA3 (Remote Device Access) libraries, sends the appropriate commands to the power converter devices. In addition to this, the software also maintains contact with and monitors the cryogenic system of every cryomodule.

Control of ACS Lines

The main feature of the software controlling the ACS lines is a finite state machine composed of eleven states. The state of the system is defined by monitoring a considerable number of parameters coming from the *line* PLCs. Once every second, the control software determines in which state the system is and, at the same time, it ensures the proper sequencing of actions which are sent to the *line* PLCs, interpreting commands and processing them in order to bring each ACS line to the requested state. Figure 2 shows the main states of the ACS system.

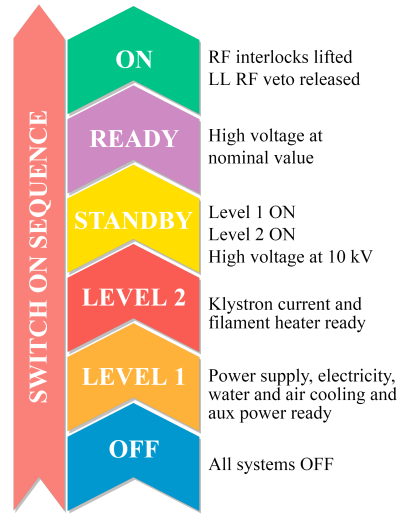

Figure 2: Main states for the ACS lines.

Additional Work

PLC FESA2 classes were replaced by SILECS interfaces and integrated into the main ACS FESA3 classes. In order to ensure a smooth transition to the new control software, the totality of persistent and operational LSA (LHC Software Architecture) [4] settings have been preserved, with the ones belonging to the old PLC FESA2 classes merged into the new FESA3 implementations. Both the *module* and the *line* classes inform users in case of faults by activating alarms in the control system and via a detailed description on the control interface. JSON is now used instead of XML as a storage format for this information. Finally, the upgrades also involved the reintroduction of RBAC rules to protect the system from unauthorized operation as well as the restoration of the logging of the most important parameters in the CERN Accelerator Logging Service.

HIGH LEVEL CONTROL APPLICATIONS

A considerable effort was invested in the migration of high level LabVIEW control applications to the Inspector rapid application development environment [5]. The migration of the twenty-five expert control applications was completed in less than six months. The Inspector applications were successfully integrated into the CERN's control system and they are currently the main interfaces used to condition, monitor and control the ACS system. Figure 3 shows one of the expert Inspector interfaces.

SOFTWARE COMMISSIONING

An ad-hoc laboratory installation composed of one *module* PLC, one *line* PLC and one *services* PLC was used to validate the system. The controllers were updated with the SILECS generated sources and three FESA classes were run on a test front-end to verify the functionality of the control software. Thanks to colleagues from the Converter Control Software section (TE-EPC-CCS) of the Electrical Power

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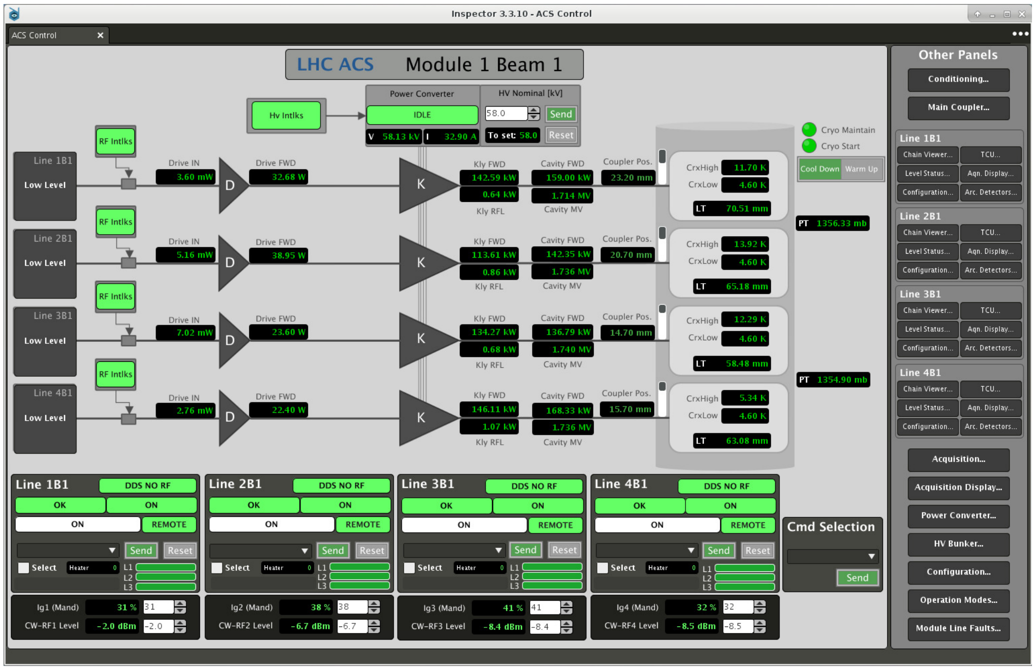

Figure 3: Main control application for the ACS system.

Converters group that supplied us with a test power converter device, it was possible to improve the power converter control interfaces.

Following this phase, the new FESA classes for both modules and lines were deployed in LHC during the first months of 2018, before the restart of the machine after the winter break. The commissioning phase before the restart allowed to further fine-tune the sequencing and to restart the LHC with no delay. The FESA class controlling the external services was deployed during the TS1 (Technical Stop 1), that took place in June 2018.

CONCLUSION

The LHC 400 MHz RF control software was renovated to follow the evolution of the CERN front-end software frameworks. Three FESA classes were developed to substitute the existing six, using the latest control libraries. Communication with PLCs was achieved via the implementation of simple SILECS interfaces, and operator and expert applications were created using Inspector.

The software was successfully deployed and fully integrated into CERN's control system, allowing LHC nominal operation until the end of Run 2. The full software stack has been validated and stands ready to restart LHC in 2021.

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