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DESIGN OF THE CONTROL SYSTEM FOR THE CERN PSB RF SYSTEM

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Abstract

The RF system of the CERN PS Booster (PSB) has been renovated to allow the extraction energy increase and the higher beam intensities required by the LHC Injectors Upgrade (LIU) project. It relies on accelerating cells installed in three straight sections of each of the four accelerating rings of PSB. Each cell is powered by one solid-state RF amplifier. This modularity is also embedded in its controls architecture, which is based on PLCs (Programmable Logic Controllers), several FESA (Front-End Software Architecture) classes, and specialized graphical user interfaces for both operation and expert use. The control system was commissioned during the Long Shutdown 2 (LS2) and allows for the nominal operation of the machine. This paper describes the design and implementation of the control system, as well as the system performance and achieved results.

INTRODUCTION

The PSB RF (Radio-Frequency) system was entirely replaced in the framework of the LIU project, to ensure the performance required for the High-Luminosity Large Hadron Collider (HL-LHC) project. In conjunction with the hardware renovation, a state-of-the-art control system was developed and commissioned to ensure the system's optimal operation.

OVERVIEW OF THE SYSTEM

The PSB machine consists of four superimposed rings, and the acceleration of particles is ensured by the new wideband Finemet RF system [1, 2], which is installed in three straight sections of the machine. In each sector two groups of Finemet cells are installed per ring, resulting in structures composed of forty-eight cells per sector. Figure 1 shows one of such structures before installation in one of the sectors. The new RF system thus consists of a total of one hundred and forty-four cells, each with independent power supplies, amplifiers and control electronics. Air and water cooling distribution are shared by the cells in each sector.

HARDWARE CONTROL

In order to ensure the safety of the system, which consists of accelerating cells, amplifiers, power supplies and auxiliary services such as cooling, machine vacuum and fieldbus communication, an advanced industrial control and interlocks system was developed. Each structure installed in a sector is controlled independently through one PLC and measurement and control cards (AI – analog input, AO – analog output, DI – digital input, DO – digital output) tailored to the equipment installed. The control program is structured to follow a sequence of data acquisitions, each authorizing

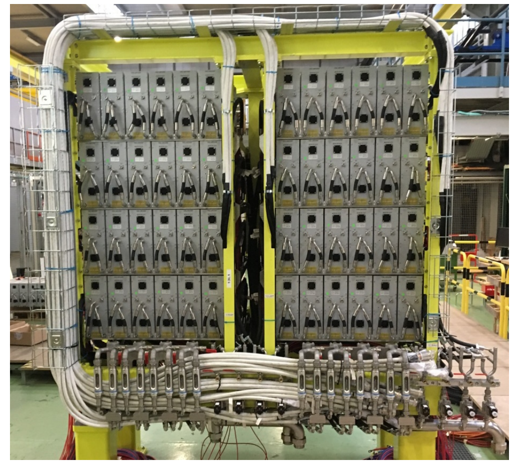

Figure 1: One of the three structures of the new PSB RF system before installation (source: CERN).

the start of the next step and ensuring that all necessary conditions are met before the RF can be pulsed. The control sequence is composed of sub-sequences, which span from overseeing general services to granting authorization for RF pulsing on a cell.

Control Sequence

Level 1 The initial part of the first level of the sequence runs checks on the fieldbus communication, water temperature and pressure, water leaks and machine vacuum. In the event of any equipment failure within this segment, an immediate shutdown of the RF system is triggered in the affected sector to ensure safety and prevent potential hazards. In the latter part of the sequence, the water cooling of the amplifiers is started independently for each ring, such that any fault happening in this stage only affects the specific ring and does not influence the operation of the others. Moreover, the program runs ventilation system checks. Any malfunctions exclusively impact the cells connected to that specific ventilation, ensuring that the neighboring cells within the sector remain unaffected.

Level 2 At this stage the designated power is distributed to the cells. Each cell is controlled independently, allowing for power redistribution among cells in the event of a malfunction as long as the minimum required power is attained. The power redistribution is made possible thanks to an automated procedure which is presented later in this document. The first step of this stage is the check of the position of the sector safety key. If this key is either removed or placed in the safety position, no power is sent to any of the cells within the relevant sector, thereby allowing safety conditions for

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interventions on the sector. In the second step, the system assesses the cells' ability to operate correctly. The operation of each cell is halted if a specific number of faults have occurred, thanks to a fault counter which can only be reset by an expert. As a third step, the temperatures of the cells are checked to ensure they fall within a specified range, thus protecting against any malfunction of the cooling system, for example a foreign object being trapped in the cooling pipes. As a final step, checks are performed on the status of the amplifiers' electronics, the auxiliary power supplies (24 V-28 V/15 A), and the main power supplies (50 V/200 A). Furthermore, the sequence verifies whether the current remains within the programmed maximum limit established by the expert, checks the integrity of the amplifiers' fuses, the statuses of the gap relays, and the temperatures of equipment racks situated around the cells. Once the sequencing steps are completed, permission to pulse the RF on the cells is granted. When a fault occurs on a cell, only the faulty cell is switched off and all other cells in the sector continue operating normally.

Radiation Monitoring

In order to assess the condition of the Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFETs) in the amplifiers and determine whether they received excessive radiation, the PLCs monitor several parameters, including the transistors' bias voltage, drive currents, and final currents. If a MOSFET has accumulated excessive radiation, the bias voltage is lowered in order to maintain a consistent final current. The PLCs measure voltages and currents from all forty-eight amplifiers within a sector in under 1 millisecond. The RF pulse has a duration of roughly 800 milliseconds, during which the voltages and currents reach their peak values.

Local Control

A local user interface was designed within the PLC, featuring a touchscreen that allows experts to perform the setting up of the equipment and to verify that all the necessary conditions are met for RF authorization in the cells.

REMOTE CONTROL

At CERN, industrial controllers such as PLCs can be seamlessly integrated into the control system through the SILECS (Software Infrastructure for Low-level Equipment Controllers) framework, formerly known as IEPLC (Industrial Ethernet for PLC) [3]. This framework serves as an abstraction layer, ensuring efficient data exchange with controllers from various manufacturers. This interoperability is achieved by defining specific SILECS interfaces that act as intermediaries for data exchange with the controllers. Notably, the installation of the new PSB RF system called for the development of three distinct SILECS classes, each designed to fulfill specific functions, in alignment with the system's modular structure. The developed interfaces allow for the individual control of sectors, rings and cells, along with the general services they require for their nominal operation. The system's modularity is preserved through the higher software layer: three FESA [4] classes expose comprehensive hardware information, enabling both the remote monitoring and operation of the entire system.

High-Level Sequencer

The fine-grained control capabilities required the implementation of automation to ensure the efficient operation the system. To this end, a FESA class implements a sophisticated sequencer. In conjunction with the system-wide control, the software allows the individual control of each group of cells installed in each ring. This software is responsible for transmitting commands to cells, rings and sectors. The operations are run in parallel to ensure optimal time efficiency. Furthermore, the software continuously publishes diagnostic information, which are then stored in the NXCALS logging database [5]. Finally, it provides active monitoring of hardware failures and automatically notifies experts, thus reducing intervention times and consequently maximizing the availability of the RF system.

Automatic Voltage Control

The control system features an additional level of automation. Another FESA class is responsible for dynamically adjusting the voltage functions sent to the low-level RF system within each sector based on the current number of active cells. The software effectively compensates for and redistributes the voltage across various sectors, besides promptly notifying operators in case the active cell count in a sector drops below the minimum required for nominal operation or the limits for the programmed voltage are exceeded, aiming at improving even more the availability of the RF system.

Radiation Logging

MOSFET radiation measurements are conducted daily over an approximately 40-minute period and stored on a logging server. A FESA class acquires the data and exposes them to the NXCALS logging service for later analysis and studies.

CONTROL APPLICATIONS

Numerous control GUIs (Graphical User Interface) were developed to facilitate the seamless operation and remote management of the equipment. The authors opted for the Inspector [6] IDE (Integrated Development Environment) to create comprehensive panels containing the necessary information and controls. The use of Inspector enabled the system's modularity to be maintained up to the application layer by allowing the development of generic panels capable of dynamically adapting to different data sources. Consequently, this resulted in the development of a single panel per structure, i.e. one for all sectors, one for all rings and one for all cells. Furthermore, a global panel was developed to provide situational awareness of the RF system to both operations and expert teams, alongside another panel offering remote control of the system. Figure 2a shows the

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(a) Global sector panel (b) Sector panel (c) Cell panel

Figure 2: PSB RF system Inspector panels.

global panel for the cells installed in the sector 5 of the PSB, whereas Fig. 2b and 2c present two examples of the generic panels displaying information of sector 5 and cell 1 in ring 1 of sector 5.

COMMISSIONING

Following the completion of the RF system installation, a software control system was developed. An extensive series of tests and refinements were undertaken in cooperation with system experts to optimize the software. The project was deployed and commissioned in 2021. The control system is effectively facilitating the operation of the PSB accelerator since, enabling the successful acceleration of particles during the current LHC (Large Hadron Collider) Run 3.

CONCLUSION

A comprehensive control system was developed to operate the novel RF installations in the PSB accelerator. The software allows RF experts to easily control the equipment, both locally from PLCs touch panels and remotely, fully exploiting the whole CERN control system stack. An extensive control sequence is implemented in the PLCs and allows the supervision of any aspect of the RF system. Multiple FESA classes communicate with the industrial controllers and allow for a time-efficient remote exploitation of the system. The whole software control system was successfully commissioned during LS2 and is presently used to operate the PSB RF system.

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REFERENCES

[1] M. Paoluzzi *et al.*, "Design of the new wideband RF system for the CERN PS booster", CERN, Geneva, Switzerland, Rep. CERN-ACC-2016-308, 2016.

[2] M. Paoluzzi *et al.*, "The new 1–18 MHz wideband RF system for the CERN PS Booster", CERN, Geneva, Switzerland, Rep. CERN-ACC-2019-120, 2019.

[3] F. Locci and S. Magnoni, "IEPLC framework, automated communication in a heterogeneous control system environment", CERN, Geneva, Switzerland, Rep. CERN ACC-2013-0232, 2013.

[4] M. Arruat *et al.*, "Front-End Software Architecture", in *Proc. ICALEPCS'07*, Oak Ridge, TN, USA, Oct. 2007, paper WOPA04, pp. 310–312.

[5] J. P. Wozniak and C. Roderick, "NXCALS - Architecture and Challenges of the Next CERN Accelerator Logging Service", in *Proc. ICALEPCS'19*, New York, NY, USA, Oct. 2019, pp. 1465–1469. doi:10.18429/JACoW-ICALEPCS2019-WEPHA163

[6] V. Costa and B. Lefort, "Inspector, a Zero Code IDE for Control Systems User Interface Development", in *Proc. ICALEPCS'17*, Barcelona, Spain, Oct. 2017, pp. 861–865. doi:10.18429/JACoW-ICALEPCS2017-TUPHA184