TUPDP091

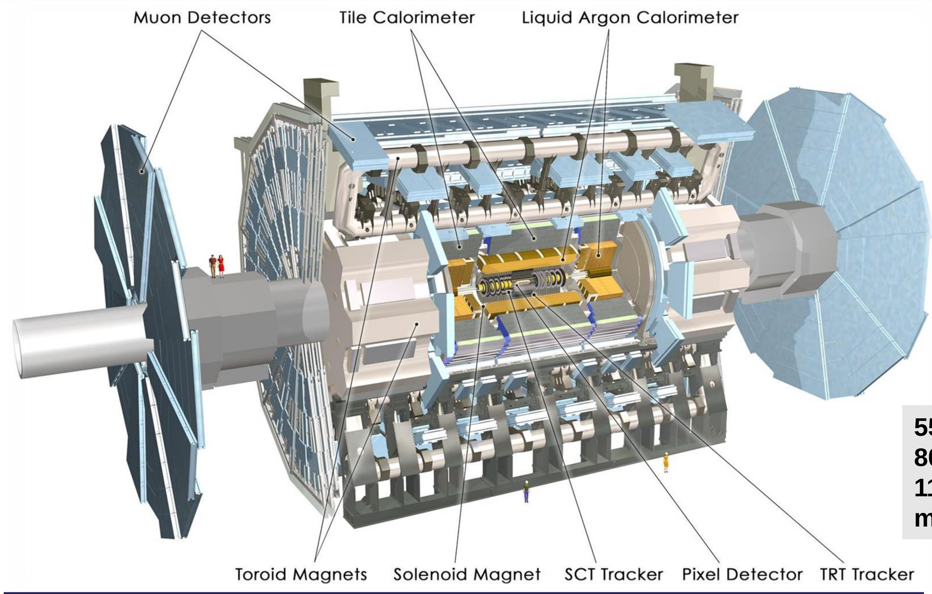
Upgrade Of The Process Control System For The Cryogenic Installation Of The CERN LHC Atlas Liquid Argon Calorimeter

C. Fluder, C. Fabre, L. Goralczyk, M. Pezzetti, A. Zmuda, CERN, Geneva, Switzerland
K. Mastyna, AGH University of Science and Technology, Kraków, Poland

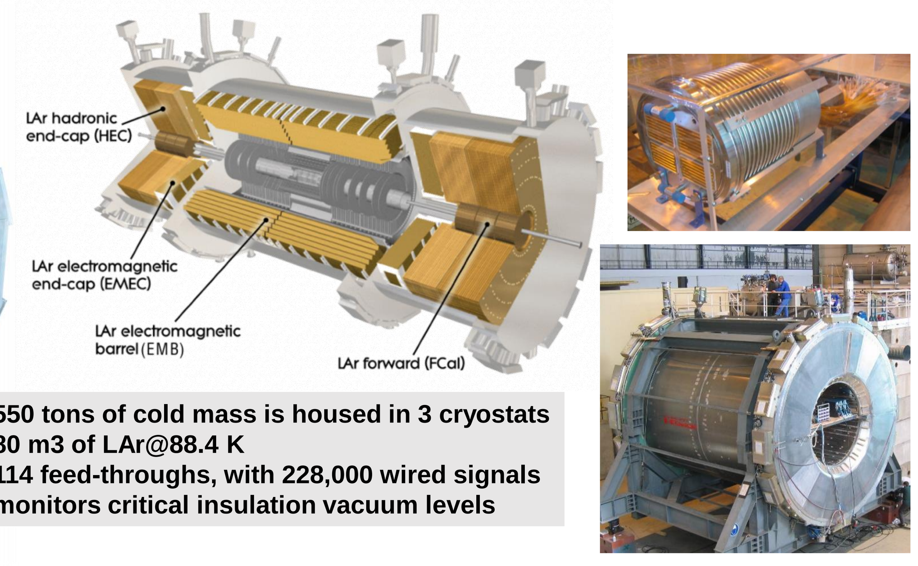
Abstract

The ATLAS (LHC detector) Liquid Argon Calorimeter is classified as a critical cryogenic system due to its requirement for uninterrupted operation. The system has been in continuous nominal operation since the start-up of the LHC, operating with very high reliability and availability. Over this period, control system maintenance was focused on the most critical hardware and software interventions, without direct impact on the process control system. Consequently, after several years of steady state operation, the process control system became obsolete (reached End of Life), requiring complex support and without the possibility of further improvements. This led to a detailed review towards a complete upgrade of the PLC hardware and process control software. To ensure uninterrupted operation, longer equipment lifecycle, and further system maintainability, the latest technology was chosen.

ATLAS LHC Detector

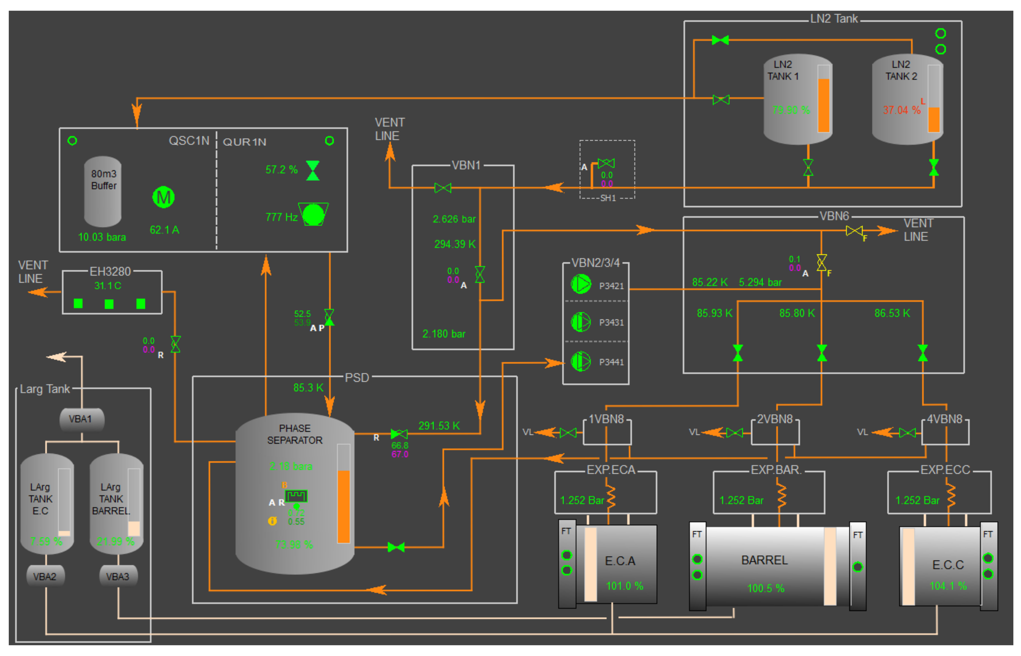


Detector overview



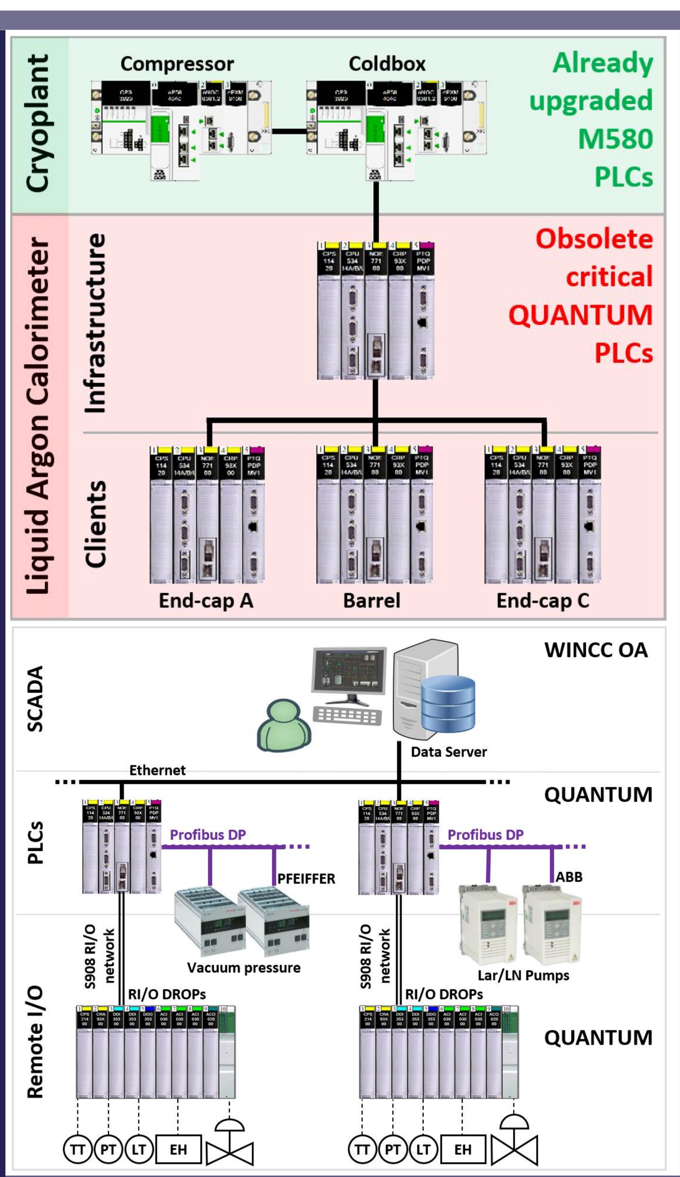
Liquid Argon Calorimeter

Cryogenics



The LAr cryogenic installation is designed to ensure uninterrupted functioning and safe handling of large quantities of liquid argon in underground areas. Its dedicated LAr control system is classified as critical due to these requirements. In addition to controlling nominal cryogenic conditions and protecting the feed-throughs it also monitors critical insulation vacuum levels. In case of degradation of such vacuum, indicating a potential liquid argon leakage and oxygen deficiency hazard, **the control system triggers alarms for personal safety** (cavern evacuation, air ventilation system, fire brigade) **and for material safety** (Detector Safety System interlocks).

Legacy Control Architecture



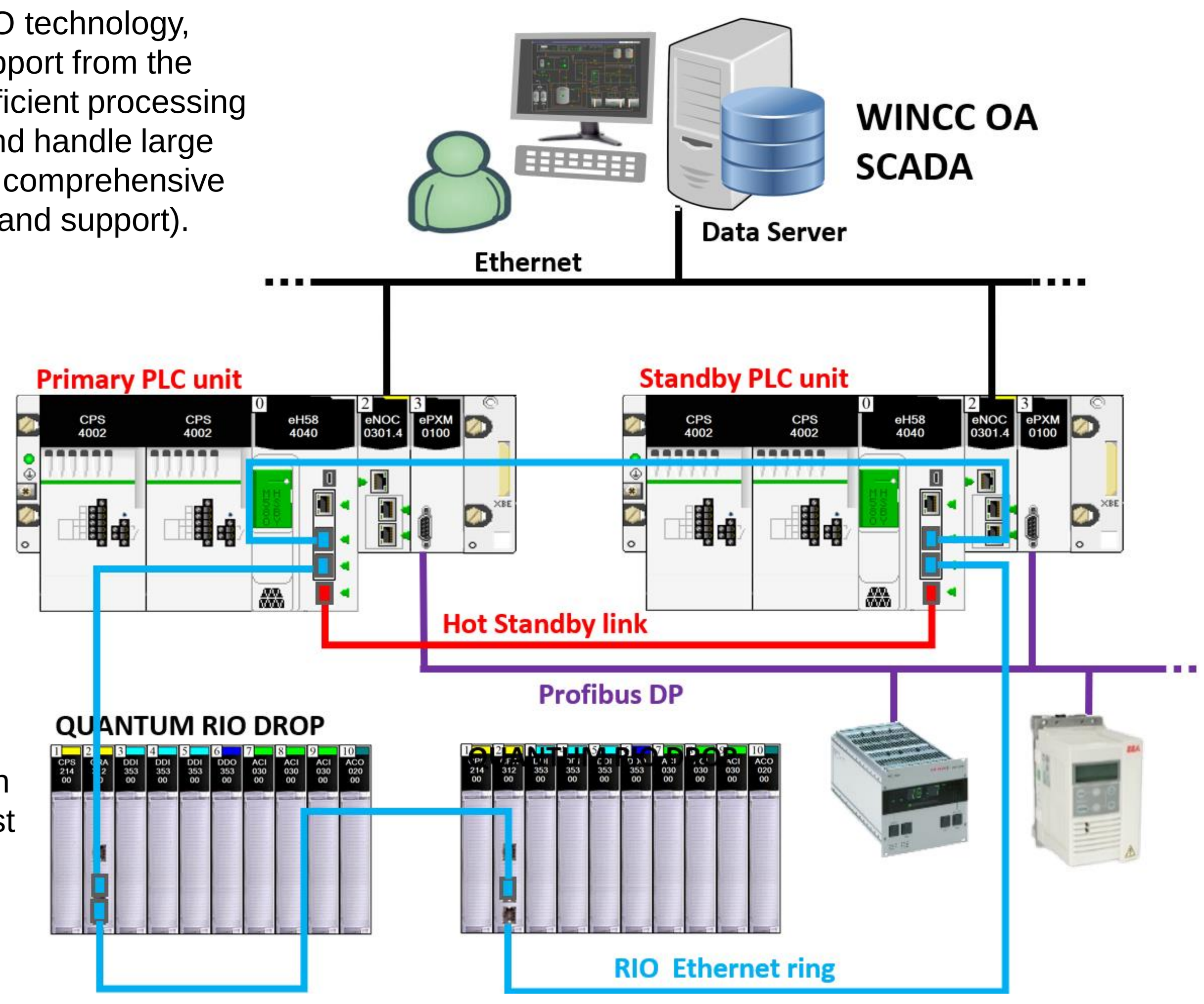
Hardware Selection / Validation & New Redundant Architecture

Criteria: compatibility with used Quantum Remote I/O technology, assurance of at least a 20-year product life cycle, support from the new CERN UNICOS CPC6 framework (UCPC6), sufficient processing power to accommodate frequent software updates and handle large control applications with thousands of RIO channels, comprehensive diagnostic features (essential for efficient debugging and support).

Redundant system hardware configuration:

Function	Model	Firmware
Ethernet rack x 2	BME XBP 0602	1.0
Redundant PS x 4	BMX CPS 4002	1.9
Hot Standby CPU x 2	BME H58 4040	3.1
Ethernet CP x 2	BME NOC 0301.2	2.2
Profibus DP CP x 2	PME PXM0 100	1.001
RIO DROP IM	140 CRA 312 00	2.7

Test bench To validate the new redundant configuration, a dedicated modular test bench, allowing to reproduce of the full configuration for each of LAr production PLCs, was setup in the lab. The test bench consists of mobile racks equipped with new redundant PLCs, Remote I/O Drops and Profibus DP network with TPG300s and VFDs.

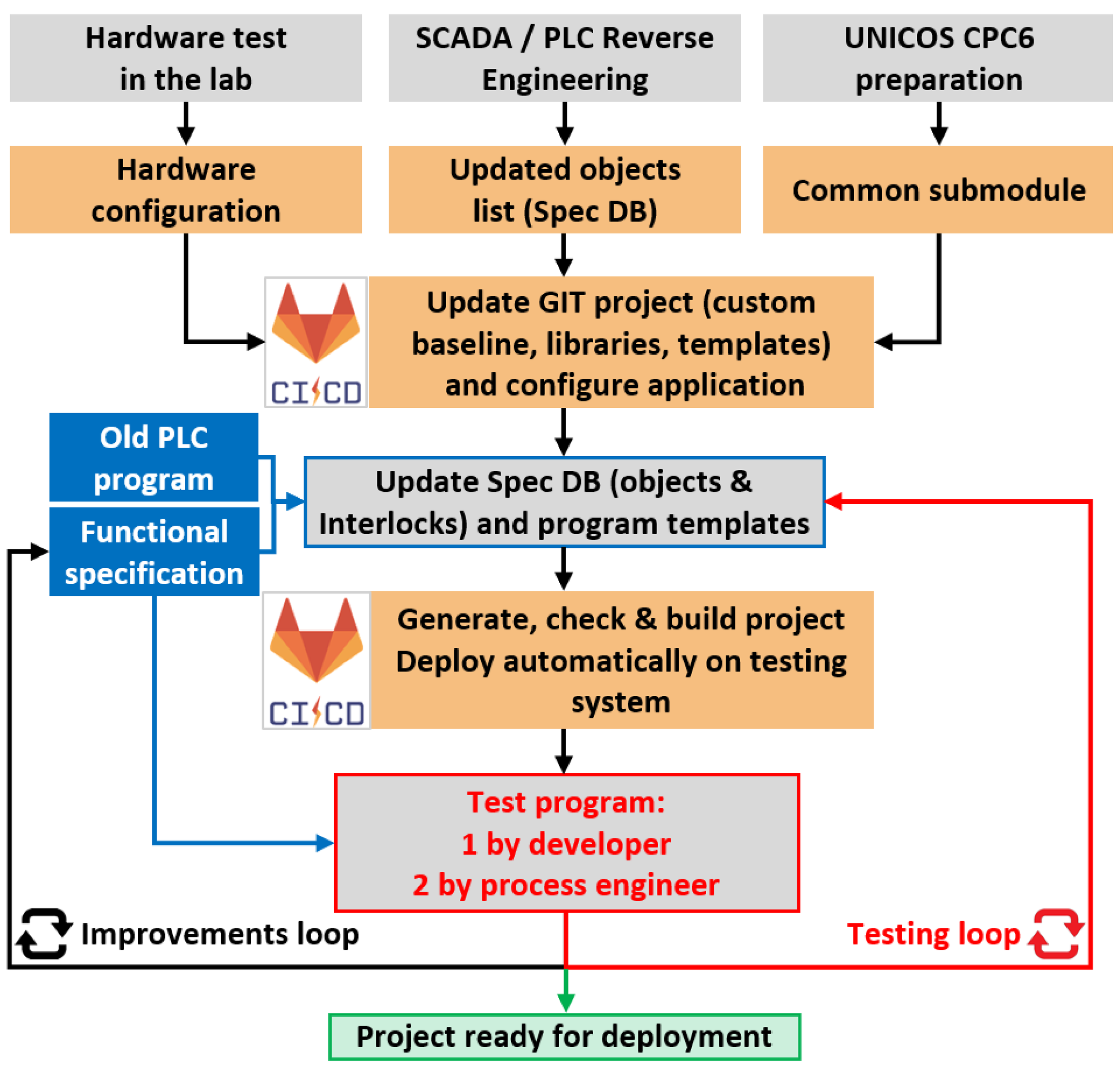


Testing protocol: involved simulating different types of primary PLC failures and verifying the transparency of PLCs swaps. The configuration for each control system was tested individually. Before launching all tests, the firmware for all components had to be updated. All new systems were tested with a program execution cycle set as periodic with a time of 100 milliseconds. The average program execution cycle, with the complete configuration, oscillated around a few milliseconds. Even for the largest infrastructure control system, which includes 10 RIO Drops and pump's VFDs on Profibus DP, no reduction in control system performance was observed.

Faulty scenarios tested: - loss of electrical power on one or both power supplies; - CPU stopped by command from console, programming error or by removing from the rack; - perturbation of Ethernet and Profibus DP communication by unplugging cables or removal cards from the rack.

In the final configuration, only swap from the primary to the secondary unit is allowed. This triggers a 1st line support intervention. Once the primary unit is restored, the swap back is done manually from the console.

Software Re-implementation and Testing



Engineering workflow

The development of the LAr control software was based on the unified software production process presented in **THPDP065**. Since the software production is fully automated, the main tasks of the developers, were to provide a tested PLC hardware configuration, complete the UCPC6 objects list, and program code templates. Each commit to the GitLab repository triggers CI pipelines that include project generation, checks, builds, and automatic deployment to the PLC-SCADA testing environment.

Development principles: - the object specification lists are updated with the current process settings (reverse engineering); - the PLC is programmed using the Structural Text language easily tracked in a version control system; - use a common template for repetitive process functions, such as the 114 feed-throughs.

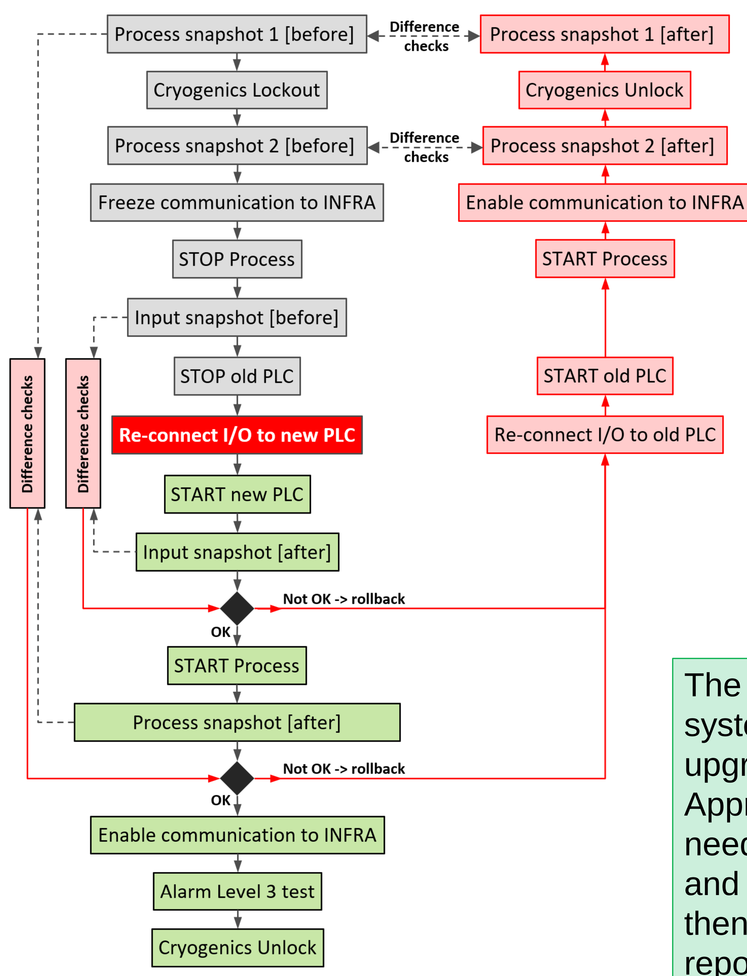
Implementation improvements: - all unused controller objects were identified and removed and at the same time 210 PID controllers were reprogrammed using templates; - the number of available spare objects was also revised and readjusted to allow for future software modification; - 1700 process alarms (interlocks), including those hard-coded in PLCs, were identified, classified and programmed according to the current UCPC6 classification; - 300 process parameters previously hard-coded in the PLCs were implemented as standard parameter objects; - data structures exchanged between all PLCs have been unified and completed; - 60 sequential function charts were fully animated in the supervision

The testing process was performed in three consecutive steps by three different teams. Initially, the preliminary tests were carried out by the developer. This was followed by detailed testing and validation conducted by the cryogenic process engineer responsible for the installation. Finally, the last round of tests was undertaken by the cryogenic operation team. For each subsystem, all process phases and various scenarios were simulated to ensure that the software performs as intended and meets the specified functional requirements.

Deployment

Preparation Before preparing the deployment procedure, the cryogenic process engineer conducted a detailed **intervention risk analysis.** This analysis examined each system function, predicted possible failure modes, evaluated the potential impact of failure on the system, assessed the criticality of failures, identified possible causes of failure, and outlined preventive and protective compensation measures. Then a **detailed implementation procedure** for the planned PLC upgrade was prepared together with the cryogenic process engineer and validated with cryogenic operation and ATLAS detector teams. This procedure includes: the sequence of PLCs upgrade, a day-by-day plan, mandatory preconditions, the deployment workflow, and step-by-step implementation procedure (checklists) for both clients and infrastructure.

Strategy: - completely test hardware, code, and implementation procedure on the mirror;- install, configure and test in parallel to the existing and operating control system, all new control system; - prevent coactivity with any other intervention; - as a preventive measure, lock-out key cryogenic items; - limit process interruptions max. 12 hours; - implement one PLC at a time; - plan one-week interval between PLC upgrades for feedback from the operations team.



Deployment workflow

The performed risk analysis, the prepared intervention procedure, the adopted strategy, and the implementation of the defined requirements allowed us to limit the most critical part of the intervention to steps illustrated on the deployment workflow, where the crucial point is the re-connection of the RIOs from the old to new control system.

The LAr calorimeter control system was successfully upgraded in February 2023. Approximately six hours were needed to replace each PLC and restore the process. Since then, no issues have been reported, and the old system has been decommissioned.

Conclusions

The defined upgrade strategy, along with the substantial effort in all project phases, allowed for a smooth and problem-free upgrade of one of the most critical cryogenic control systems at CERN. Thanks to all the implemented improvements, the LAr control system has become more robust and immune to PLC crashes, simultaneously increasing the overall reliability of the cryogenic system. Any future modifications to the control logic can be easily implemented due to the automation of software production. With the help of UCPC6, control system support and maintenance can be efficiently handled, and operators can benefit from a unified process interface and updated logic specifications.

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