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UPGRADE OF THE CMS ECAL DETECTOR CONTROL SYSTEM DURING THE CERN LARGE HADRON COLLIDER LONG SHUTDOWN II*

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Abstract

As part of the Compact Muon Solenoid (CMS) experiment, the Electromagnetic Calorimeter (ECAL) Detector Control System (DCS) is undergoing a large software and hardware upgrade during the second long shutdown (LS2) of the CERN Large Hadron Collider (LHC). The DCS software running under the WinCC Open Architecture (OA) platform, required fundamental changes in the architecture as well as several other upgrades on the hardware side. The extension of the current long shutdown (2019-2021) is offering a unique opportunity to perform more updates, improve the detector safety and robustness during operations and achieve new control features with an increased modularity of the software architecture. Starting from the main activities of the ECAL DCS upgrade plan, we present the updated agenda for the LS2. This covers several aspects such as the different software migrations of the DCS, the consolidation of toolkits as well as some other improvements preceding the major ECAL upgrade foreseen for the next long shutdown (2025-2026).

INTRODUCTION

The CMS (Compact Muon Solenoid) [1] experiment at the CERN Large Hadron Collider (LHC) is a general multipurpose detector designed primarily to probe proton-proton and heavy ion collisions. The detector is built around a huge superconducting solenoid of 6m internal diameter providing a magnetic field of 3.8 T. A silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter and a brass scintillator hadron calorimeter are located within the solenoid volume. Muon detectors are embedded in the steel flux-return yoke outside the solenoid.

The electromagnetic calorimeter consists of about 76,000 $PbWO_4$ scintillating crystals and a lead/silicon preshower. The detector is conventionally sub-divided in three main partitions: Barrel (EB), Endcaps (EE) and preshower (ES). The EB is organised in 36 super-modules forming a cylinder around the proton-proton interaction point. Each super-module contains 1700 crystals arranged in four modules. The EEs are the structures which close both ends of this cylinder with each of them formed by two half disks named DEEs and containing 3662 crystals. The ES consists of two circular structures placed in front of the EEs. More details on the CMS ECAL detector can be found in [2].

The challenging constraints on the design of the ECAL required the development of a complex sophisticated Detector Control System (DCS). The ECAL DCS has successfully supported ECAL operations since the commissioning phase of the detector contributing to an efficient data collection during Run 1 and Run 2 operations. Detector maintenance at CMS closely follows the LHC calendar with major upgrades postponed to special times, known as the Extended Year-End Technical Stops (EYETS) and the LHC Long Shutdowns (LS). We are currently in the second major long shutdown LS2 [3] since the start of the LHC. Initially planned to last two years until April 2021, due to the ongoing COVID-19 pandemic the LS2 was extended by one year. During the LS2 both hardware and software upgrades were performed, as described in [4]. In this paper we focus on the software upgrades, including the software migration which allowed the ECAL DCS to be up-to-date with the latest versions of the control platform and frameworks.

This paper is organized as follows. After describing the CMS ECAL DCS, we describe the software upgrade performed during LS2 where different upgrades are reported in four subsections. An additional section reports on the reorganization of the notification system of the ECAL DCS, which also took place during LS2. Finally, we summarize the contents in the last section.

THE CMS ECAL DCS

The ECAL DCS was designed to ensure an autonomous control and monitoring of the working conditions of the ECAL detector and to guarantee the detector is properly powered and able to collect data when the LHC is operational. The ECAL DCS is organised according to the detector services it provides, where the latter can be categorized in four different groups: powering services, safety services, environmental monitoring services (humidity and temperature) and external services. The ECAL DCS architecture is schematically shown in Fig. 1.

The DCS software supervises the interaction among the different subgroups mentioned above and runs on three DELL blade servers installed with the Windows Server 2008 R2 operating system. A redundant software replica is also available in the event of a critical failure of the primary system. The DCS software is assembled via the commercial WinCC Open Architecture (WinCC OA) control system toolkit from ETM [5] along with CERN software frameworks known as JCOP Framework [6] and components developed by the Central CMS DCS team [7]. Industry standards, as OPC Data Access (OPC DA), Modbus and

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S7 protocols for hardware communication are used. As part of such ECAL DCS migration described in this paper, the OPC DA servers have been migrated to OPC Unified Architecture (UA) servers.

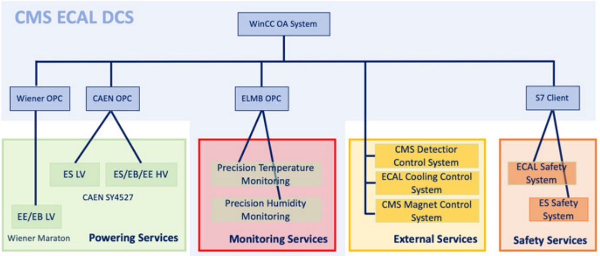

Figure 1: ECAL Detector Control System (DCS) architecture including its connection with other services. Inspired by [5].

Commands are sent to the ECAL subsystems via a Finite State Machine (FSM) [9], the core of each control system at the LHC. Thanks to a logical grouping of DCS subsystems into a hierarchical tree-like structure, the FSM enables a simplified representation of the DCS by introducing a set of defined states for each detector partition, for instance state ON/OFF for the ECAL EEs, and specific rules to move from one state to another. Within this architecture, the state of each sub-component is clearly summarized at higher level and high-level commands can be propagated down to individual ECAL partitions in a controlled way. This allows process variables to be summarized in a single-human-readable state and control commands to be implemented by a shifter in the CMS Control Room without a detailed expertise of the underlying hardware.

SOFTWARE MIGRATION

During the current long shutdown, the ECAL DCS had to go through some software migrations which can be subdivided into three types: WinCC OA and JCOP control framework migration, OPC UA migration and control system migration. They are described in more detail in each of the subsections below. Following these migrations, an additional review of the DCS software was also needed, as reported in the final part of this section.

WinCC OA and JCOP Control Framework Migration

This migration was centrally coordinated by the CMS DCS team, as part of a CMS-wide plan to accommodate all the CMS DCS software with the latest release of the control platforms. The plan was discussed and agreed internally in CMS in the first half of 2020. The final CMS migration took place in July 2021 with a few validation tests performed in April and June 2021 during a few days of ECAL operations.

The ECAL DCS was migrated from WinCC OA version 3.15 to version 3.16 and from the CERN JCOP control framework version 8.1.2 to version 8.4.0 [10]. WinCC OA migrations at CERN are common, as the software needs to be up to date with the latest versions ETM provides support for. Nevertheless, this specific migration required a major effort as the new version of the platform only supports a specific encoding type forcing a migration from the old type.

WinCC OA Migration. While projects in WinCC OA versions lower than 3.16 were created using the ISO-8859-1 (Latin) encoding by default, the 3.16 version only supports Unicode UTF-8 encoded projects. This is part of an attempt by ISO and the Unicode Consortium to develop a coding for electronic text that includes every existing alphabetic symbol, since the ISO-8859-1 (Latin) encoding covers ASCII characters but doesn't include several symbols frequently used in other languages different from American English or some of the most popular western European languages. Compared to the ISO-8859-1 encoding, where each symbol is represented by a single byte (character data type), in the UTF-8 project each character is represented by a multibyte encoding with 1-4 bytes. Since only a sub-set of the Unicode UTF-8 encoding is backwards compatible with the previous encoding, the ECAL DCS project required a review of all the codes to check if they were compatible with such a change. ECAL DCS source files were checked looking for non-compatible characters. Automatic tools were implemented to detect and update pieces of codes. As a result, only 11 of the 304 ECAL DCS files required such changes. They were often code comments written by international developers using special characters from languages different from American English.

While analysing the ECAL DCS codes, a special care was devoted to some strings which needed to be treated as arrays of characters for some applications. Since individual characters of these arrays must be processed as such for a proper functioning, a search for these specific arrays of characters through the ECAL DCS codes was required. A program has been developed searching for these special character-type situations, like character-type declarations or arrays of characters, allowing the discovery of pieces of codes which would have failed otherwise.

An additional effort was performed to develop a new set of Unicode standard functions, which were also ASCII-compatible. In total, the code was updated to accommodate the introduction of 11 new types of functions in the ECAL DCS project. In order to reduce transitioning periods between the two WinCC OA versions, all the ECAL DCS components were upgraded already in the legacy system 3.15 so that the development proceeded in parallel for both versions.

With respect to user's interface, special characters in the panels might not be displayed correctly if the panels were written with ASCII-compatible characters. In large projects it happens often that some elements from old panels are copied and pasted into new panels. When importing pieces of code, such as buttons etc., from panels written with the ISO encoding into new panels written with the UTF encoding, some artefacts might be generated. ETM recommended that in order to convert existing panels to the new UTF format, a conversion to *XML* files should be performed. A new XML file format for storing purposes of project panels has been adopted in WinCC OA version 3.16. Even though the previous file format could have been compatible, for consistency it was decided to convert all the existing files in the ECAL DCS system accordingly. Being the XML format also compatible with the previous WinCC OA version, an earlier deployment was already implemented in the previous WinCC OA 3.15 legacy system. As the conversion was completed, the converted panels were re-analysed via a set of tools to remove redundant declarations and correct for possible undetected conversions.

JCOP Control Framework Migration. The Joint Control Project JCOP is a collaboration between the CERN LHC experiments, the EP Department and the Industrial Group in the Beams Department at CERN aiming for a shared control system architecture used LHC-wide. As part of this mission, in 2003 the group released a common JCOP framework which allowed the configuration, the monitoring and the operation of different sub-detectors of the LHC experiments enabling communication with the Data Acquisition systems and the CERN infrastructure services, as well [11]. Updated versions are produced periodically. Following the new release of the WinCC OA platform, the JCOP group released a new version of the JCOP framework compatible with it. Thus, the ECAL DCS had to migrate the framework used in the legacy system version 8.1.2 to 8.4.0. In the previous JCOP framework versions most functions worked with no need for an explicit call of required libraries, as libraries and utilities were part of a global scope of WinCC OA. Due to performance purposes, this software design was abandoned starting from version 8.4.0 of the JCOP framework causing a review of all the source codes to explicitly call required framework libraries. This review affected not only the ECAL DCS system, but almost all the DCS systems implemented by the other CMS sub-detector groups. Given the large use of the past functionality, this required a major effort. Thus, the JCOP and CMS Central DCS teams provided the sub-detector DCS teams with specific tools for an automatic identification and modification of sources which required an update. As recommended by the JCOP framework team, the tool codePurger has been used to scan the entire ECAL DCS project searching for unresolved calls of functions and implementing automatic modifications. This resulted in the creation of a reference database which was later used for such identification and modification of sources requiring an explicit call for libraries. In total 240 code transformations were required, out of 120 source files analysed by the tool. For consistency the updated codes were also compared to previous versions proving the reliability of the tool and implemented updates.

OPC Unified Architecture Migration

Since 1996 the OPC DA standard has been successfully allowing communications between any hardware regardless of its vendor. At CERN, OPC DA has been heavily used to control and monitor a large variety of devices, which are controlled by a SCADA layer provided by WinCC OA. WinCC OA communicates via its built-in OPC driver - an OPC Client - to an OPC server, which communicates with the physical device. A schematic representation is shown in Fig. 2. Following the release by the OPC foundation of the OPC-UA specifications and implementations, CERN decided to migrate all the existing OPC DA servers to OPC UA [12]. Compared to the old OPC DA based on the deprecated Microsoft COM/DCOM, OPC UA is now based on modern industry standards making it a more compelling candidate for controlling and monitoring middleware between SCADA systems and hardware devices.

Some of the most important OPC UA highlights include:

- its platform independence being not tied anymore to Microsoft platforms,
- its improved security since it has a comprehensive security model built in securing channel client/server communication,
- its improved modelling since it has an extensive vocabulary for modelling purposes which allows to type components and express inter-component relationships.

Within the WinCC OA – OPC architecture described above, hardware addresses are encoded in the form of datapoints. Individual software components for each application are responsible for the final installation and configuration of datapoints related to that application.

The OPC UA migration in CMS took place in parallel with the WinCC OA/JCOP framework migration during summer 2021 with several validation tests performed in spring 2021. The ECAL DCS makes use of three different OPC servers to monitor and control the following devices:

1. Wiener Marathon power supplies for EE/EB Low Voltage (LV) via Wiener OPC,
2. CAEN power supplies for EE/EB High Voltage (HV) and ES LV and HV via CAEN OPC,
3. CERN-made module Embedded Local Monitor Boards (ELMBs) used for ES High Voltage monitoring, for EEs HV and for ECAL Precision Temperature Monitoring via CANOpen OPC.

The software components affected by this migration in ECAL DCS are reported in Fig. 2. Every component required a reconfiguration of the address space. This was done via an automatic tool released by the JCOP framework team for the different OPC servers. This migration also allowed for a conceptual change from a monolithic single-server configuration to a multiple-server paradigm resulting in a further splitting of the current OPC server's configuration. Benefiting from this, it was possible to anticipate some of the granularity changes which will be required for the LS3 upgrade, when the ES and EE detectors will be removed and so the related OPC UA servers. Having a more granular architecture already in place will simplify the removal operation expected for LS3.

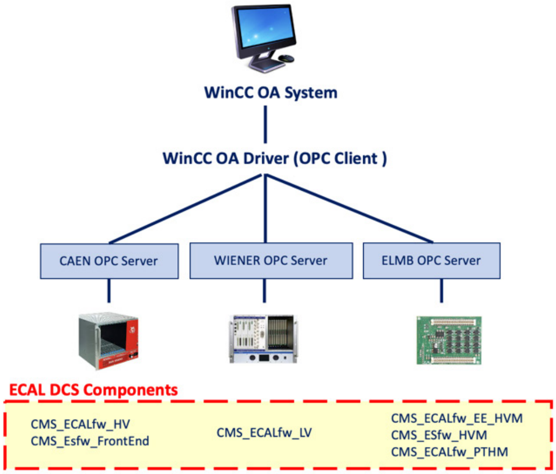

Figure 2: WinCC OA/OPC architecture used at CERN with the indication of the three different servers in use. For each type the ECAL DCS component, which had to undergo the OPC UA migration, is also indicated.

Version-control-system Migration

After having been largely used during LHC Run 2 operations, the Apache Subversion system (SVN) [13] for versioning and revision control system was officially abandoned by CERN in 2018. This forced all the LHC experiments to migrate their SVN-based projects to the Git distributed version control system, hosted by the CERN GitLab service [14]. The ECAL DCS team took this opportunity to also implement some hierarchy reorganization of the project repositories. When moving to Git repositories, the original SVN repository was split into a hierarchy of individual repositories, which were structured according to their functionality. As a result, the ECAL DCS system moved from a single repository to a set of 35 different repositories.

Additional Reviews

In this section we describe a few additional software reviews, which were needed following the migrations reported in the previous sub-sections.

When installing a specific component, some other components might be needed prior to the installation of the component in consideration. This is due to the dependency chain which must be respected for the component to be installed properly. The JCOP migration described in the previous section affected the dependency chain to be followed when installing a component. As for the other CMS DCS projects, the installation of the ECAL DCS components follows guidelines from the JCOP framework group. When installing a component, the component itself should provide all the required information respecting the needed dependencies. A specific toolkit, the ECAL DCS installation toolkit, has been developed over the past years for such a purpose. Following the software migration and the introduction of new libraries, the toolkit has been reviewed and modified to meet some new requirements, such as the new configuration of OPC UA servers.

An additional software review was also needed regarding the new OPC UA configuration for Wiener OPC. Following a hardware replacement for ECAL LV (which took place during data-taking operations in August 2021), a type mismatch in the address configuration between OPC UA and WinCC OA has been discovered. After running some tests, the default type in WinCC OA was moved from bool32 to int32 solving the mismatch. This was not observed during the validation tests in spring 2021 and became clear only after the whole migration took place. It was also reported to the CERN OPC experts for future improvements.

UPDATED NOTIFICATION SYSTEM

In parallel to the software migration, during the LS2 some work was also done to improve the current notification system. In the ECAL DCS project, components use a central tool developed by the Central DCS team for configuring alarm-based notifications. By using this tool, the system accesses the needed CERN e-group – the interface developed at CERN to manage groups – and import a list to distribute messages to its members. The ECAL DCS team has contributed to some improvements for a further e-group integration. While in the past the tool required periodic synchronizations to be fully operational, this is not needed anymore for the new version to operate. Specifically, in the past ECAL DCS notifications and recipients were part of groups – the notification groups – whose lists of recipients were also synchronized once or twice a day. Since the notification groups were used by different components to send messages, the previous centralized system allowed for multiple messages to be sent to the same group of users. During ECAL operations this might be problematic, as it becomes hard to monitor new alarms among several replicas of others. A reorganization of the notification system was designed in 2020. The new system is organised by application domains, with each of them used exclusively by a single component. This prevents the possibility of multiple messages to be sent by different components. Users can then subscribe/unsubscribe directly to an independent e-group for a specific notification domain simplifying the overall system.

CONCLUSION

After several successful years during Run 2 operations at CMS, the CMS ECAL DCS project is undergoing major modifications during the current second-long shutdown at the LHC. During summer 2021, system codes have been reviewed and modified to accommodate several software migrations ongoing in CMS, such as the WinCC OA and JCOP control framework migrations. In parallel, OPC DA servers used by the ECAL DCS project have been migrated to the new OPC UA configuration. Taking advantage of the long shutdown, additional upgrades were also performed. All the code repositories stored since the start of the ECAL DCS project have been move to the CERN Gitlab version control system and the ECAL DCS notification system has been reorganised for a more efficient functionality.

Some validation tests were performed in spring 2021, in preparation for the final migration which took place during summer 2021. The ECAL DCS system has been successfully migrated and will serve as the ECAL DCS legacy system for the Run 3 data-taking operations starting in March 2022.

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REFERENCES

[1] CMS Collaboration, “The Compact Muon Solenoid, Technical Proposal”, CERN-LHCC-94-038 LHCC-P1, CERN, Switzerland, December 1994.

[2] CMS Collaboration, “The CMS electromagnetic calorimeter project: Technical Design Report”, CERN-LHCC-97-033 CMS-TDR-4, CERN, Switzerland, 15 December 1997.

[3] M. Bernardini, K. Foraz, “Long Shutdown 2 @ LHC”, in *Proceedings of the Chamonix 2014 Workshop on LHC Performance*, Vol. 2, CERN, Switzerland, 2015.

[4] R. J. Estupiñán et al., “CMS ECAL Detector Control System upgrade plan for the CERN Large Hadron Collider Long Shutdown II”, in *Proceeding of the 12th Int. Workshop on Emerging Technologies and Scientific Facilities Controls (PCaPAC’18)*, Hsinchu, Taiwan, Oct. 2018.

[5] ETM ,`http://www.winccoa.com/company`

[6] O. Holme et al., “The JCOP Framework”, in *Proceedings of the 10th International Conference on Accelerator and Large Experimental Physics Control Systems*, WE2.1-60, CERN, Switzerland, 10-14 October 2005.

[7] R. Gomez-Reino et al., “The Compact Muon Solenoid Detector Control System”, in *Proceedings of the 12th International Conference on Accelerator and Large Experimental Physics Control Systems, MOB005*, Kobe, Japan, 12-16 October 2009.

[8] O. Holme et al., “Preparing the hardware of the CMS Electromagnetic Calorimeter control system and safety systems for LHC Run 2”, in *Proceeding of the Topical Workshop on Electronics for Particle Physics 2015*, Lisbon, Portugal, Oct. 2015.

[9] C. Gaspar, B. Franek, “Tools for the Automation of Large Distributed Control Systems”, in *Proceedings of the 14th IEEE-NPSS Real Time Conference*, Stockholm, Sweden 4-10 June 2005.

[10] R. J. Estupiñán et al., “Software migration of CMS ECAL Detector Control System during the CERN Large Hadron Collider Long Shutdown II”, in *Proceeding of CHEP2021*, EPJ Web of Conferences 251, 04007, 2021.

[11] CERN JCOP Framework, `http://jcop.web.cern.ch/jcop-framework`

[12] B. Farnham, R. Barillère, “Migration from OPC-DA to OPC-UA”, in *Proceedings of ICALEPS2011, MOPMS025*, Grenoble, France 2011.

[13] Apache Software Foundation Subversion, `http://subversion.apache.org`

[14] CERN Gitlab, `http://gitlab.cern.ch`