RE-INTEGRATION AND CONSOLIDATION OF THE DETECTOR CONTROL SYSTEM FOR THE COMPACT MUON SOLENOID ELECTROMAGNETIC CALORIMETER*

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Abstract

The current shutdown of the Large Hadron Collider (LHC), following three successful years of physics data-taking, provides an opportunity for major upgrades to be performed on the Detector Control System (DCS) of the Electromagnetic Calorimeter (ECAL) of the Compact Muon Solenoid (CMS) experiment. The upgrades involve changes to both hardware and software, with particular emphasis on taking advantage of more powerful servers and updating third-party software to the latest supported versions. The considerable increase in available processing power enables a reduction from fifteen to three or four servers. To host the control system on fewer machines and to ensure that previously independent software components could run side-by-side without incompatibilities, significant changes in the software and databases were required. Additional work was undertaken to modernise and concentrate I/O interfaces. The challenges to prepare and validate the hardware and software upgrades are described along with details of the experience of migrating to this newly consolidated DCS.

INTRODUCTION

The CMS ECAL DCS has been in operation for several years and has successfully supported all periods of data acquisition from LHC particle collisions since 2009. During the intense schedule of activities when LHC is running, there has been limited possibility for upgrades and modernisation of the system in recent years. The current LHC long shutdown (LS1) provides an excellent opportunity to upgrade ageing hardware and move away from legacy, sometimes unsupported, software versions. This will ensure that an optimal system is in place to provide efficient control and monitoring of the detector in the following years as LHC goes back into operation.

The LS1 introduces a different set of challenges to those during LHC operation. As many other CMS systems are also being upgraded simultaneously, there are several constraints on the availability of externally delivered resources such as electricity and cooling. This severely restricts the opportunities for certifying system modifications, which motivates the need for extensive testing and validation in laboratory conditions prior to final deployment.

CONTROL SYSTEM OVERVIEW

The CMS ECAL DCS is designed to enable simple and reliable operation of the calorimeter, with monitoring to ensure that the detector is functioning within acceptable operating parameters. The detector powering is provided by commercial power supplies from CAEN [1] and Wiener [2], which feature low-level, built-in protection logic in case of local malfunction. Hardware front-ends are deployed to readout the probes that monitor the environmental conditions in the detector volume, such as temperature and humidity levels. Programmable Logic Controllers (PLCs) are used to implement standalone safety systems, which are also monitored by the control system in order to complement the information about the status of the detector.

The controls software runs on Microsoft Windows and is implemented with the SIMATIC WinCC Open Architecture (WinCC OA) commercial supervisory control software toolkit [3] and the CERN-developed JCOP Framework [4]. The interface between the controls servers and the hardware is realised through standard physical network layers such as CAN, RS-485 and Ethernet using vendor specific and industrial protocols including S7, Modbus and CANopen. At the software layer, Open Platform Communications Data Access (OPC DA) servers are widely used to provide a high-level abstract interface to the hardware information, reducing the complexity of the integration of the hardware data into the supervision software layer.

Full details of the architecture of the CMS ECAL DCS have been reported previously [5].

MERGING APPLICATIONS

Major upgrades and improvements are being made to the supervision layer and to the software environment. One of the most significant changes is the adoption of a new generation of Dell Blade servers, which are considerably more powerful, allowing the software to run on fewer machines. Previously the system ran across fifteen computers and the target with the new servers is to reduce to three.

The DCS software was originally designed as several standalone components, with each intended to run on a separate machine. This limited coupling, between applications on different computers, eased the original integration of the system. It was not originally envisaged to run the independent software components on the same machine, so no guidelines were followed to avoid incompatibilities between the applications. For instance, two particular areas of interference were: the use of non-unique WinCC OA persistent storage variable names, known as *data points*, and the re-use of interface bus

*Work supported by the Swiss National Science Foundation

ISBN 978-3-95450-139-7

identifiers, which were numbered from zero in most applications.

Due to the complexity involved in merging the applications, this was selected as the main priority to address in the list of scheduled software changes. Following an earlier analysis project [6] that involved a detailed inspection of the implementation and functionality of each piece of software, many of the incompatibilities between components were exposed. To guarantee the successful removal of all issues, including those not identified in the analysis procedure, side-by-side installations were performed in laboratory conditions.

The compatibility issues were resolved and now any combination of components is possible. The final decision on where to install each component was taken in order to avoid the increase in complexity that could occur by running many heterogeneous communication systems on the same computer. Using this principle, one machine was targeted to run all CAEN power supply applications and a second was allocated for the complete Wiener power supply control. A third machine was selected to handle all the environment monitoring data and the interface to the safety systems. A fourth machine is kept as a spare to allow further load distribution in case of performance issues that could not be identified outside of the CMS environment. The preferred final architecture of the system is shown in Figure 1.

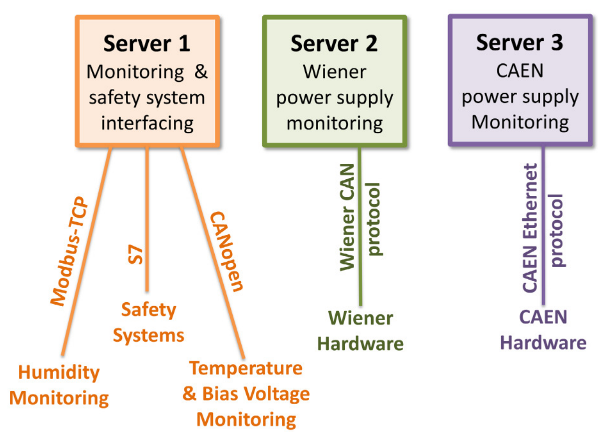

Figure 1: A diagram of the new CMS ECAL DCS architecture with the software running on three servers.

MERGING DATABASES

All DCS applications rely on access to two types of external Oracle database, namely the Configuration Database (ConfDB) and the Conditions Database (CondDB). The purpose of the ConfDB is to hold sets of data defining the objects that form the running application instances and to store recipes, which are groups of settings that can be applied in a running system. When an application is created, the object configuration is loaded from the ConfDB to create the fully operational application instance. The CondDB is used to store the archive of important process variable values.

Originally, in order to facilitate the independent development of the CMS ECAL DCS applications, multiple schemas in the CondDB and ConfDB were used. However, due to the design of WinCC OA and the JCOP FW, it is more straightforward to develop and operate with a single unified schema for configuration data and another for the conditions data. For this reason, effort was dedicated towards this database schema merging activity. Additionally, a data cleaning process was applied to remove legacy data items that were no longer useful.

The official interface to the ConfDB is through WinCC OA instead of direct access to the database tables. In order to follow this recommended approach, the merging procedure involved loading each configuration set into a temporary WinCC OA application and then saving the data into the new, unified schema. This required significant effort because the saving process is an intricate task of identifying the relevant objects from the WinCC OA application to save to the destination ConfDB.

The merging of historical data in the CondDB firstly involved matching the table definitions in each of the independent source schemas. By unifying the structure of tables in each schema, the data could then be merged by exporting from each source and importing into the target CondDB. Care had to be taken to modify internal identifiers to ensure that every object in the merged database was uniquely represented.

SOFTWARE UPGRADES

Following the reorganisation and merging of applications and databases, the remaining software related improvements were addressed. The operating systems were upgraded to Windows Server 2008 R2 for the production machines and Windows 7 for the development and test setups. In itself, this change did not have any direct consequences on the functionality of the CMS ECAL DCS software.

The first of the software toolkits to be upgraded was WinCC OA; moving to the latest 3.11 SP1 release. Simultaneously, the latest release of the JCOP Framework, version 5.0.1, had to be adopted due to version dependency issues. Due to earlier work to consolidate the CMS ECAL DCS software, the increased reliance on standard JCOP and CMS application programming interfaces (APIs) limited the direct interaction with the underlying WinCC OA version. Despite this, there were still some cases where incompatibilities arose. Most of these issues could be identified from static analysis of the code, such as searching for strings that represented process names that had changed between WinCC OA releases.

As a final step, the OPC servers delivered by the hardware providers must also be updated to the latest versions. Due to changes in the underlying OPC development kits, issues such as case sensitivity of OPC items have been seen to cause problems. All the naming incompatibilities were identified and the OPC configuration data in the ConfDB was updated for all affected devices accordingly.

ISBN 978-3-95450-139-7

REGRESSION TESTING

As described in the previous sections, many fundamental changes have been made to the CMS ECAL DCS software and databases. A testing tool was developed, in order to handle the frequent deployments of software in the laboratory and to perform deep analysis to check the validity of the resulting installations. This approach was based on concepts previously developed for automated regression testing in the CERN Industrial Controls & Engineering group [7] and the DCS team of the TOTEM experiment [8]. The intention is to define a specific image of the installed system as a valid reference configuration. After any subsequent DCS software modifications or changes in the underlying software platforms and frameworks, the system can be re-created and the image of this new instance can be compared with the reference.

The chosen method for imaging the WinCC OA applications was to export the complete list of data points along with their values and configuration details. These objects are exported in plain text format to a set of files that, by default, contain considerable information that is unique to a given application instance, such as internal identifiers, file paths, component version numbers and timestamps. In order to make the test insensitive to these values, a specific fuzzy comparison mechanism was built using the Python scripting language. This comparator works by removing the objects and values that are instance specific, leaving only the objects which should remain constant from one deployment to the next. Furthermore, arbitrarily ordered lists are sorted alphabetically to ease the comparison of the images. The resulting files can then be checked against the reference files to verify the integrity of the newly created application instance as shown in Figure 2.

This method of imaging and comparing applications is very sensitive to changes in the CMS ECAL DCS software and configuration database contents. It is also quite susceptible to other changes in the underlying frameworks and software packages as new versions of these components can create new WinCC OA data points that did not exist previously. There is no automatic way to differentiate between changes caused by ECAL-level modifications and those from other external software products, leading to a number of false-negative test results. This introduces a certain overhead in the analysis of a failed test result of whether or not a difference with the reference application is indicative of a real problem. In contrast, due to the high sensitivity of the test, a positive test result gives considerable confidence that the latest versions of the software and ConfDB are working correctly.

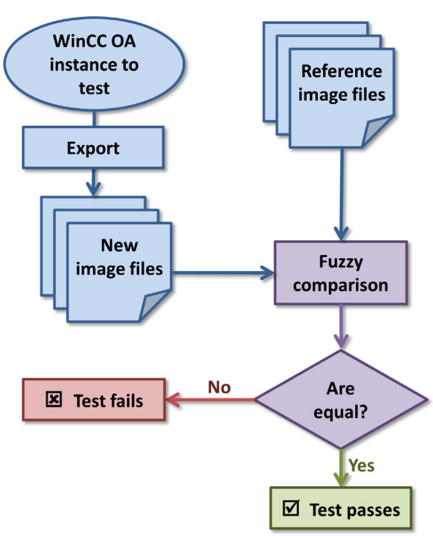

Figure 2: The procedure for validating a test instance of an ECAL DCS application against a valid reference.

Automated Testing Environment

To ease the execution of the tests, a nightly build mechanism was established using the Jenkins Continuous Integration (CI) server [9]. Three computers were allocated to represent the three production servers in CMS. Jenkins is used to start essential external processes, trigger an installation of each application, extract an image of the newly created instances and then execute the validity checking against reference images. Before each laboratory test deployment of the applications, the latest code is checked out from the CMS ECAL DCS Subversion repository. In the test environment, the ConfDB containing the application configuration details is a frequently updated replica of the production database.

HARDWARE INTERFACE CHANGES

The consolidation of the DCS onto fewer computers enables and requires additional merging at the hardware interface layers. Most of the protocols for communicating with the hardware can be carried over Ethernet and it is straightforward to switch these connections between the old and new servers. The exception to this is the hardware that communicates via CAN, where the connection to the servers has been via a USB-CAN converter. The converter currently in use is the USB-CANmodul16 from SYS TEC Electronic GmbH [10], which provides two independent 8-port CAN adapters.

In the previous architecture, the number of CAN bus connections was limited by the performance constraints of the servers. As the minimum granularity of the SYS TEC adapters is 8 CAN ports per USB connection, this led to a significant underusage of the hardware resources available, as demonstrated by the example of the Wiener power supply interfacing shown in Figure 3. With the new servers, processing power limitations are relaxed, making it possible to re-organise the CAN buses to make more efficient and balanced use of the ports offered by the SYS TEC USB-CAN adapters.

Further upgrades to the CAN interfacing are planned, by identifying suitable hardware to allow the CAN data to be transferred via Ethernet. Investigations and tests have been carried out in collaboration with the CMS DCS team and the CERN Industrial Controls & Engineering group.

ISBN 978-3-95450-139-7

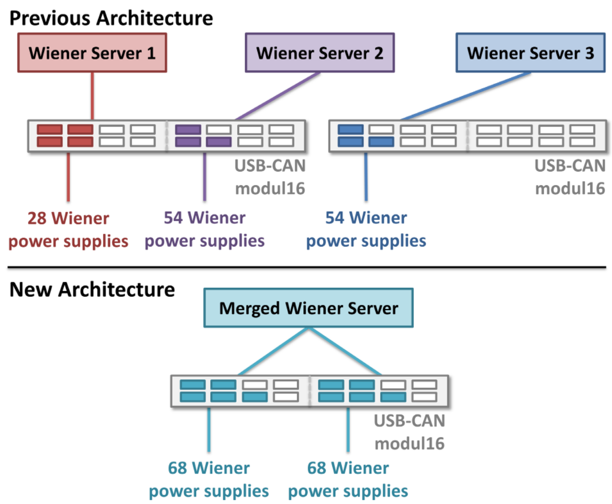

Figure 3: The interfacing of Wiener devices via USB and CAN in the old and new ECAL DCS architectures. Unused CAN ports are marked in white with grey outline.

The first device to be analysed was an Ethernet-USB adapter that would interface the existing SYS TEC devices to an Ethernet network. This approach has delivered some promising results, although there are some residual issues that are hard to resolve due to the increased complexity of the readout chain, including software drivers and hardware from multiple commercial vendors. Alternative investigations have focussed on a direct Ethernet-CAN adapter that would completely replace the existing interfaces and provide a simpler readout chain.

CURRENT STATUS

The updated, modified and merged software layer has been successfully deployed into the new servers and inspected for completeness and validity. The previous generation of computers continues to host the production system needed for the reduced schedule of activities during LS1. The new applications are awaiting full scale testing which cannot currently be performed as much of the detector powering system is switched off. As more devices are switched on, further performance tests will be carried out to prove that the three new servers are sufficient to handle the load. The fourth machine remains available if the tests are negative and additional computing resources are needed.

Once the dimensions of the new architecture are finalised, the next issue to be addressed during LS1 is the implementation of redundancy at the software level. This will require doubling the number of servers and running each application instance on two servers at the same time, according to the redundancy principles of WinCC OA. The redundancy will provide continuity of operation in cases where one of the redundant partners fails, increasing the overall robustness of the system. The other software changes are complete, pending the final tests, and the topic of software redundancy will now become the primary focus of development.

CONCLUSIONS

The CMS ECAL DCS has made significant progress in migrating to the latest generations of software and hardware technologies. Through careful analysis and modification, the incompatibilities between the independent DCS applications have been removed and an optimal distribution of these applications has been deployed onto three of the new servers. The external databases and hardware interfaces have also been merged to become simpler and more efficient due to the possibilities offered by the new consolidated architecture.

An automated, nightly build testing environment was constructed to ensure that the unintended impact of software and database changes could be rapidly detected, assessed and corrected if necessary.

The issues of Ethernet interfacing for CAN buses and redundant WinCC OA applications provide further possibilities for improving the system during the current shutdown of the LHC. With the changes already implemented and the developments still to come, the CMS ECAL DCS will be more modern, efficient and robust, providing a reliable system for the forthcoming restart of physics operations in 2015.

ACKNOWLEDGEMENTS

With thanks to the Central CMS DCS team for merging the CMS ECAL DCS conditions database schemas.

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