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To cite this article: D Di Calafiori *et al* 2011 *J. Phys.: Conf. Ser.* **331** 072044

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The CMS Electromagnetic Calorimeter Detector Control System

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Abstract. This paper presents the Detector Control System (DCS) designed and implemented for the Electromagnetic Calorimeter (ECAL) of the Compact Muon Solenoid (CMS) experiment at CERN. The focus is on its distributed controls software architecture, the deployment of the application into production and its integration into the overall CMS DCS. The knowledge acquired from operational issues during the detector commissioning and the first phase of the Large Hadron Collider (LHC) physics runs is discussed and future improvements are presented.

1. Introduction

The Compact Muon Solenoid (CMS) [1] is one of the multipurpose particle detectors of the Large Hadron Collider (LHC) [2] accelerator at CERN. The CMS experiment is composed of eight sub-detectors [1]: Pixel, Tracker, Preshower and Electromagnetic Calorimeter (ECAL), Hadronic Calorimeter (HCAL), Drift Tubes (DT), Resistive Plate Chambers (RPC) and Cathode Strip Chambers (CSC). Each sub-detector has a customized control system designed for their specific needs and centrally managed by the CMS Detector Control System (DCS) [3].

Herein, the ECAL DCS [4,5] architecture will be presented with emphasis on its distributed software, the integration under the central CMS DCS and its evolution during the past years until the achievement of a stable and robust configuration. In accordance with the layout of the detector, the control system was partitioned into three main sections: the ECAL Barrel (EB), the ECAL Endcaps (EE) and the ECAL Preshower (ES). Several aspects regarding the deployment of software into production, the control system performance during more than three years of support to the detector, the software analysis project which aims to reduce the long term maintenance effort through homogenization of the software and further improvements foreseen for the coming years will be discussed.

2. The Detector Control System Architecture

The focus of this section is on the ECAL DCS software and in order to ensure a proper understanding of its distributed architecture and partitioning, a short description of the DCS hardware configuration is presented.

2.1. Hardware configuration

The ECAL DCS hardware [4,5] is divided in two categories:

- Control and Monitoring: comprises the Low Voltage (LV) and Bias Voltage (BV) powering systems, the VERSA Module Eurocard (VME) crate control and the Programmable Logic Controller (PLC) based safety systems for the EB/EE (ESS) [4,5] and for the ES;
- Monitoring: handles temperature, relative humidity and water leakage detection (WLD) sensors, the latter being available only on the EB and EE. The EB/EE and ES cooling system hardware is not controlled by the ECAL DCS and is therefore classified under the monitoring category.

All ECAL partitions follow the same DCS concept. The EB and EE DCS hardware are very similar and therefore are merged into common sub-systems while the ES DCS hardware is treated separately.

2.2. Distributed system software architecture

Divided in several independent components, the ECAL DCS software was developed on PVSS II 3.8 SP1, a Supervisory Control and Data Acquisition (SCADA) software from ETM [6] and using the Joint Controls Project (JCOP) [7] framework, developed in collaboration with CERN and the LHC experiments. The software for the complete system runs on 14 computers, with all applications connected to the main supervisor through a simple interface of well defined actions and summarized states. A simplified diagram of all ECAL DCS components is presented in figure 1.

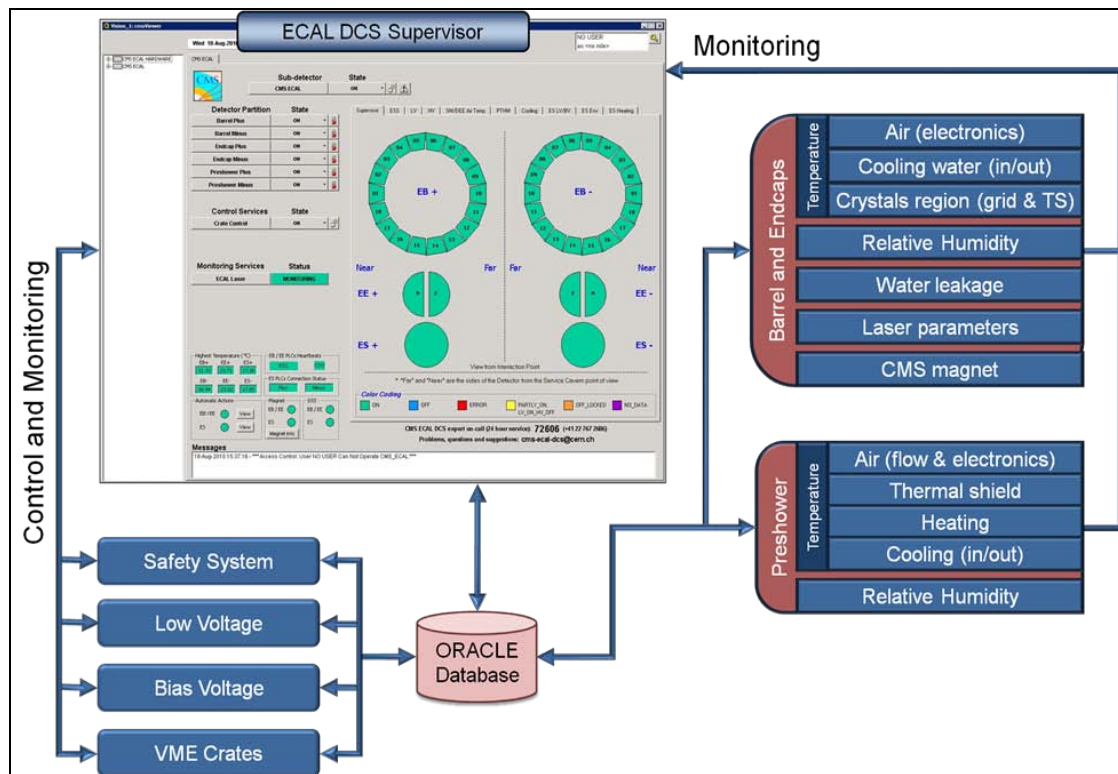


Figure 1. The ECAL DCS Software Structure

The current software architecture has one core component per sub-system, with exception of the ES, where all sub-systems are combined into a single monolithic component. Each application has its own hierarchical structure representing the layout of the sub-detector, which is used to summarize the hardware state and to allow actions to be sent simultaneously to groups of hardware. All applications are able to archive and read back their data from ORACLE databases. A short description of each application, including their main functionalities is presented below.

- 2.2.1 *Supervisor*. Responsible for all interactions between the sub-systems applications, as well as for the interconnection with the CMS DCS layer. This application handles the automatic actions to switch off the detector partitions in case of problems, as well as to switch the ES BV to the proper state according to the LHC beam mode. In addition, it monitors several parameters such as external connections status, FSM health and ORACLE database archiving modes, issuing alerts to the CMS DCS operators in case of detected issues. A screenshot of the Supervisor main panel can be seen in figure 1.
- 2.2.2 *ES sub-systems*. Due to its separate development and recent integration under the ECAL Supervisor, all ES sub-systems are currently handled by a single component. This application controls and monitors the ES safety system, the 200 ES LV channels and the 192 ES BV channels. The temperature monitoring uses 160 sensors, covering temperatures of the air, of the heating system, of the thermal shield and of the cooling. The relative humidity (RH) is monitored by 16 sensors. Due to readout hardware limitations, 56 temperatures sensors are read by another sub-system and their data is published to the ES application via the CERN developed Data Interchange Protocol (DIP).
- 2.2.3 *EB/EE Safety System (ESS)*. Monitors the ESS PLC health and its inputs and outputs. Through this application it is possible to manually set and clear interlocks to the powering and cooling systems.
- 2.2.4 *EB/EE Low Voltage*. Controls and monitors the 860 LV channels (684 for the EB and 176 for the EE).
- 2.2.5 *EB/EE Bias Voltage*. Controls and monitors the 1240 BV channels (1224 for the EB and 16 for the EE).
- 2.2.6 *EB/EE Air Temperature Monitoring*. This application is responsible for the monitoring of 352 air temperature sensors, installed in redundant pairs, close to the front-end electronics inside the EB and EE. Error states based on tighter temperature limits, compared to the ones set up on the ESS PLC, are used to trigger shutdown actions via software prior to safety actions.
- 2.2.7 *EB/EE Precision Temperature and Humidity Monitoring (PTHM)*. The ECAL crystals thermal stability monitoring, the EB/EE cooling water input and output temperatures and the RH monitoring are the main features of this application. In addition, ES temperature sensors are read and published via DIP to the ES application.
- 2.2.8 *EB/EE Cooling Monitoring*. The ECAL DCS has no control over the EB/EE cooling. The cooling monitoring application subscribes to all the relevant data published via DIP by the cooling control system, such as temperatures and flow values. Using tighter limits compared to the ones set up on the cooling PLC, this monitoring application is able to generate error states prior to safety actions, allowing the DCS to issue a protective action to ensure a smooth shutdown of the concerned partition.
- 2.2.9 *Laser Monitoring*. This application reads data published by the standalone laser control application via the Distributed Information Management (DIM) protocol. All relevant laser parameters are readout and displayed on a single panel accessible via the ECAL Supervisor. Its main function is the re-publication of the CMS Magnet Control System (MCS) data to the laser control application, which is used to shutdown the laser lamps during magnet ramps.
- 2.2.10 *VME crate control*. Based on a central CMS service, this application is part of the ECAL Supervisor and allows the operator to switch the EB and EE VME crates on and off. An extension of it is foreseen, to include the ECAL laser and the ES VME crates.

3. The ECAL DCS in the CMS Environment

The ECAL DCS was developed envisaging a smooth integration under the CMS DCS, following the general central guidelines and with a wide use of centralized services and components. A simplified diagram containing its interactions with the CMS DCS environment is presented in figure 2.

The software (full components or patches) deployment into production is performed through a central web-based tool called “component handler”, available via an online portal designated *CMS Online* [3]. The same portal provides several other experts tools, such as the remote management of PVSS systems, monitoring of processes running on the Windows based ECAL DCS host computers and user groups administration tools for controlling access to the ECAL DCS.

General information of the experiment, including the sub-detector states, rack monitoring and magnet data, is made available by the CMS DCS through *CMS Online* and also published via DIP.

A redundant DIM Name Server and an Access Control Server are also provided and supported by the CMS DCS. All ECAL DCS applications use a 3-role (monitor / operator / expert) access control concept and the main ECAL DCS partitions can be operated in local ECAL or global CMS modes.

The ECAL DCS uses ORACLE databases for storage of configuration and detector conditions data. The archived data can be accessed either through the PVSS applications or via a CMS Web Based Monitoring (WBM) service, the latter being accessible from anywhere.

The knowledge and experience acquired with the ECAL DCS operations is shared within the wider context of CMS DCS.

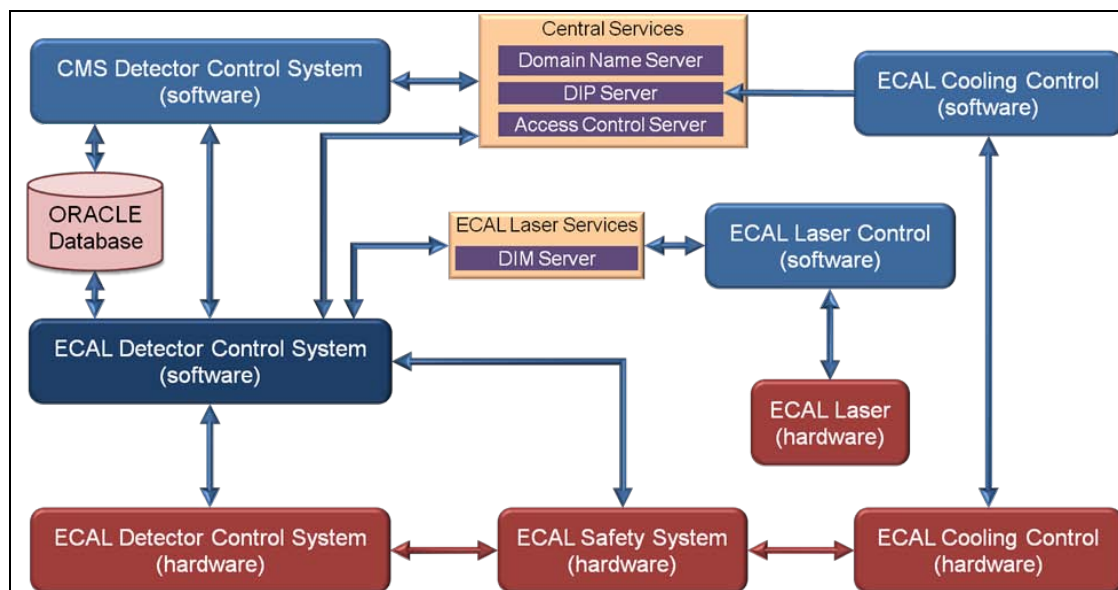


Figure 2. The ECAL DCS in the CMS DCS Environment

The ECAL has five protective layers. The operator intervention is an option that is always available, as the operator has the right and responsibility of moving the detector to a safe state at all times. The ECAL DCS protection mechanisms are the next layer, monitoring and evaluating all conditions in real time to identify possible harmful scenarios to the detector. If the ECAL DCS layer is not prepared to cover a specific condition, the ESS layer will react at the hardware level according to the ECAL safety matrix. In case all the layers described so far are compromised and therefore incapable of performing the proper action, the system relies on the CMS Detector Safety System (DSS) layer to perform the proper protection procedures. As a last resort, the operator can manually intervene by pressing the DSS Emergency Button, which will trigger, on the hardware level, a full stop of all powering services to the detector according to the ECAL part of the DSS safety matrix.

4. The performance during the first phase of LHC proton-proton physics

The ECAL control system has overcome many challenges since its deployment into production, starting from problems faced due to the inability of testing it in a full hardware scale prior to the installation in the CMS environment, followed by a large amount of requests for additional features and the continued need for adaptation in order to be consistent with the CMS DCS operational requirements.

In terms of off-detector hardware, all problems were solved within the expected response time, avoiding at all times any considerable delay to the data taking. The experience from the past years was used to set up an optimal spares stock for the control and safety systems, the latter also relying on the CERN PLC Critical Stock, a centralized 24/7 service for PLC parts replacement.

As expected, on-detector hardware issues were also faced and handled in the best way to guarantee that the control and monitoring of ECAL is never compromised. Find below a few examples:

- A small fraction of the EB BV channels showed a considerable increase in the power consumption. These channels were re-configured via DCS to allow higher currents and consequently maintain the powering to all sensors connected to these lines.
- Whenever the magnetic field is present, an on-detector issue triggers the overvoltage protection of one of the EE LV channels. The DCS has the ability of monitoring and setting inhibits for all Trigger Towers (TT) powered by this channel, meaning that this channel could be inhibited and all the other channels of this power supply remain unaffected.
- Part of the ES sensors showed a considerable increase on the BV currents. Until the pattern was well understood, the corresponding current limits were increased via DCS and additional monitoring mechanisms were implemented in order to ensure prompt reaction before they reached an unacceptable value. Currently the mechanism for disabling these sensors is only available on the hardware and requires a human intervention. A project to make this function available via DCS is ongoing.
- Temperature and humidity sensors with unreliable readings were removed from the automatic actions trigger, as well as from the alerts mechanisms. Their amount and location do not compromise the coverage of the detector monitoring.

The protective mechanisms implemented on the DCS layer took care, in the majority of the cases, of switching the detector off prior to the safety actions whenever harmful conditions, such as cooling failures, were detected. At all times, the safety systems reacted properly, moving the detector to a safe state and preventing it to be switched on without an expert intervention.

The ECAL DCS group has provided since the very beginning of the operations at the CMS site a 24/7 expert on-call service, covering both hardware and software issues.

5. The ECAL DCS Software Analysis Project

Initially the ECAL DCS applications were developed in a standalone approach, taking into account only their sub-systems needs. Once the deployment into production started, a project to integrate all applications into the common ECAL DCS supervisor was undertaken, moving the focus from the sub-systems to the full detector needs.

The evolution of the software components was based on the initial design of each subsystem. Consequently, the system has achieved a stable configuration with several different approaches to perform similar tasks.

In order to ease the long term ECAL DCS software maintenance and to make the system even more robust, a project called “The ECAL DCS Software Analysis” was carried out. Through deep studies of the current code, reviews of procedures, mechanisms and identification of similarities, the aim was to homogenize the control system by creating common components and standards for defined procedures.

The outcomes of the analysis have indicated several common features that can be standardized across the complete ECAL DCS. As a result, the software can now be re-factored accordingly,

providing modular components, each with a clearly defined function, which can be re-used throughout the ECAL DCS. This will reduce duplication of effort and shrink the code base to minimize the expert knowledge required to keep the system operational in the long term.

A common solution for storing individual application configuration parameters, used during software re-installations and for applying new settings, is foreseen. This will allow for a reliable, rapid and automated creation of an application in case of a DCS computer failure, reducing the resulting down time.

An analysis of the current load on the DCS computers has proven the feasibility of combining applications currently running on different computers. With certain improvements, identified during the analysis, the applications will no longer be restricted to their current host computers, making it easy to re-distribute the applications amongst the DCS computers. The initial estimation is to move from a schema of 14 computers to only 6, maintaining the required performance with a more even distribution of the processing load and reduced risk of failure.

6. Conclusion

The ECAL DCS has achieved a fully operational, very stable and robust configuration, enabling the maximum availability of the detector during the first phase of collisions at CMS.

The system is very well adapted to the CMS DCS environment, profiting considerably from all the centralized services and providing valuable inputs to the improvements of the central and other sub-detectors systems.

By re-configuring services and adding extra features, all issues faced were overcome without compromising the detector control or its monitoring coverage.

The consolidation and homogenization of the ECAL DCS applications, based on the outcomes of “*The Software Analysis Project*”, will guarantee and improve the system maintainability throughout the lifetime of the experiment.

7. Acknowledgements

The authors would like to thank the Swiss National Science Foundation and the Ministry of Science and Technological Development of Serbia for the financial support.

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