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The upgrade and re-validation of the Compact Muon Solenoid Electromagnetic Calorimeter Control System

O. Holme¹, P. Adzic², D. Di Calafiori¹, G. Dissertori¹, L. Djambazov¹, D. Jovanovic², W. Lustermann¹, S. Zelepoukine^{1,3}

¹Institute for Particle Physics, ETH Zurich, 8093 Zurich, Switzerland

²University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences

³University of Wisconsin-Madison, WI 53706, U.S.A.

E-mail: oliver.holme@cern.ch

Abstract. The Electromagnetic Calorimeter (ECAL) is one of the sub-detectors of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) at CERN. The Detector Control System (DCS) that has been developed and implemented for the CMS ECAL was deployed in accordance with the LHC schedule and has been supporting the CMS data-taking since LHC physics runs started in 2009. During these years, the control system has been regularly adapted according to operational experience and new requirements, always respecting the constraints imposed on significant changes to a running system. Several hardware and software upgrades and system extensions were therefore deferred to the first LHC Long Shutdown (LS1). This paper presents the main architectural differences between the system that supported the CMS ECAL during its first years and the new design for the coming physics runs after LS1. Details on the upgrade planning, including the certification methods performed in the CMS ECAL DCS laboratory facilities, reports on the implementation progress and the expectations for the post-LS1 system are highlighted.

1. Introduction

The ECAL of CMS detects and measures the particles released from high energy collisions in the LHC with 75,848 lead tungstate scintillator crystals and over 4,000 silicon sensors. The photodetectors that measure scintillation light and the silicon sensors require bias voltage, ranging from 60-800 volts. To acquire data from the detector, in excess of 100kW of electrical power must be delivered to the on-detector readout electronics via low voltage power supply lines. To extract the heat dissipated in the detector, a powerful water cooling system is used.

The CMS ECAL DCS controls and monitors the power supplies and provides monitoring of the environmental conditions within the detector volume to ensure that it is running within acceptable parameters [1]. Programmable Logic Controller (PLC)-based safety systems are responsible for interlocking the detector sub-systems in case of safety critical conditions. The CMS ECAL DCS can take preventive actions before such conditions occur.

The hardware and software layers of the CMS ECAL DCS are implemented using industrial technologies as well as those resulting from CERN collaborations. Custom software and hardware is designed and developed as required to complete the final working system.

To reflect the structure of the detector, the CMS ECAL DCS divides the detector into three logical partitions, the barrel (EB), the endcaps (EE) and the preshower (ES). Each partition of the detector is divided into two halves, referred to as the plus and minus sides.



Throughout the first period of LHC physics data acquisition, from 2009 to 2013, there were very limited opportunities to upgrade hardware due to the strict schedules of accelerator and detector activities. Now, due to LS1, there are many months in which major upgrades can be performed. It is essential to replace ageing hardware, resolve issues discovered in the previous years and to make use of new technologies to ensure that the DCS continues to perform optimally and can provide the required standards of functionality and robustness for the next phase of LHC physics.

2. Hardware evolution

2.1. Precision temperature monitoring

The temperatures in EB, EE and parts of ES are monitored by a precision temperature monitoring (PTM) system consisting of 512 Betatherm 100k thermistors and precise reference current sources that are read out with 18 Embedded Local Monitor Boards (ELMB) [2]. The ELMB is a radiation tolerant front-end electronics board that can read 64 analog inputs, supporting the CANopen protocol to interface with the DCS software. When exposed to very large radiation doses, the ELMB is known to draw large currents [3] which could place too much load on the PTM power supply network. To provide increased robustness, against ELMBs drawing high currents and other failures such as shorts to ground, a powering system that would enable the isolation of individual problematic powering channels was designed. Due to time constraints and limited opportunities to apply major upgrades, this system was not deployed previously.

In preparation for LS1, the new powering architecture was designed (figure 1), based on two identical powering networks to distribute power to the plus and minus sides of the PTM system. Each ELMB requires three different power supplies to power the analog input electronics, the microcontroller and the CAN bus controller respectively. In addition, the PTM system requires powering for the reference current sources. These four different types of load are powered by separate power supplies, eliminating any possible interference between these components of the system. In addition, arrays of switchable terminal blocks provide an adaptable distribution, enabling single problematic power lines to be isolated to avoid degrading other parts of the PTM system.

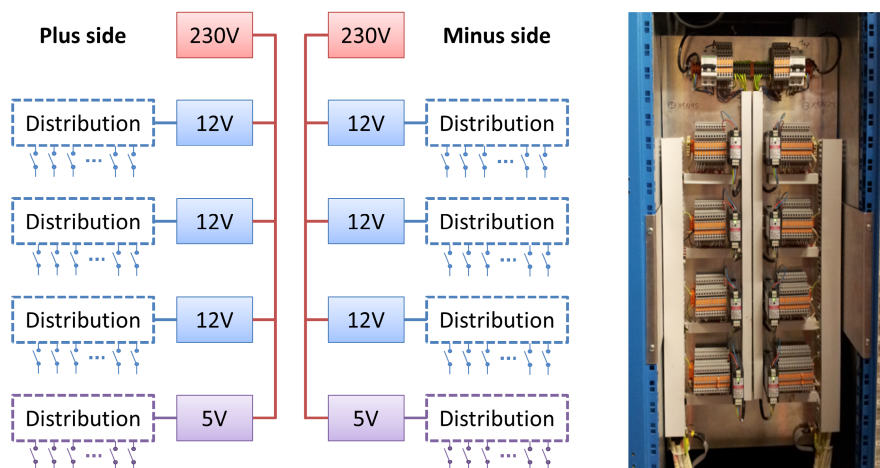


Figure 1. A schematic and photograph of the new PTM powering architecture.

2.2. Detector volume relative humidity monitoring

The ES is designed to run at temperatures down to -15°C and the air humidity in these partitions must be carefully monitored to determine the dew point at which condensation could occur. Due to significant risk of damage to the detector caused by condensation, the ES humidity probes are monitored directly by the ES PLC safety system.

The EB and EE operate at a temperature of $+18^{\circ}\text{C}$ and a continuous flow of nitrogen limits the humidity in the detector, so the issue of dew point is not so significant for EB and EE detector safety.

However, the monitoring of humidity is still important as rising humidity can be useful to understand the environmental conditions inside the detector.

The ES humidity monitoring system is able to monitor the full range of expected humidity levels and no upgrade has been required. The original EB and EE readout system could only distinguish relative humidity readings above 60% from the probes installed in the EB and EE, which excluded monitoring of the nominal, low humidity conditions. In order to extend the range of humidity monitoring, an improved readout system was designed by the CMS Belgrade group, which features new electronics to excite and readout the probes in the detector [4].

2.2.1. EB and EE humidity readout calibration. The new readout hardware was delivered during 2012 and was tested in CMS during the end of the physics data taking period that preceded LS1. The tests were successful and demonstrated that the hardware and integration into the software layer worked as expected. Before final deployment, it was necessary to characterise the input channels, which feature independent signal amplifiers, in order to provide precise mapping between the ADC (analog-to-digital converter) value and the actual humidity level reported by the probe.

An automated calibration setup (figure 2) was designed and implemented with a commercial humidity generator from Rense, which is capable of creating humid air in the range of 10-80% relative humidity. This humidity in the regulated volume is adjusted with a manual selection knob on the device, which does not offer any possibility for automatic control. To overcome this limitation, a custom automation system was implemented using the open-source Arduino platform [5] and a servo with custom mechanics to move the control knob to the desired position.

A commercial, calibrated humidity probe with temperature readout and correction was monitored with an ELMB to provide a precise reference value. This was inserted into the regulated humid volume of the humidity generator along with four probes of the same type as used in the CMS ECAL. These four probes were carefully selected to be as similar to each other as possible and were connected to the humidity readout unit with 100m long cables, which are representative of the longest cable lengths in the CMS ECAL humidity readout system. The whole setup of the humidity generator, humidity probes and Arduino were placed in an aluminium lined polystyrene box to avoid sudden changes in the environmental conditions.

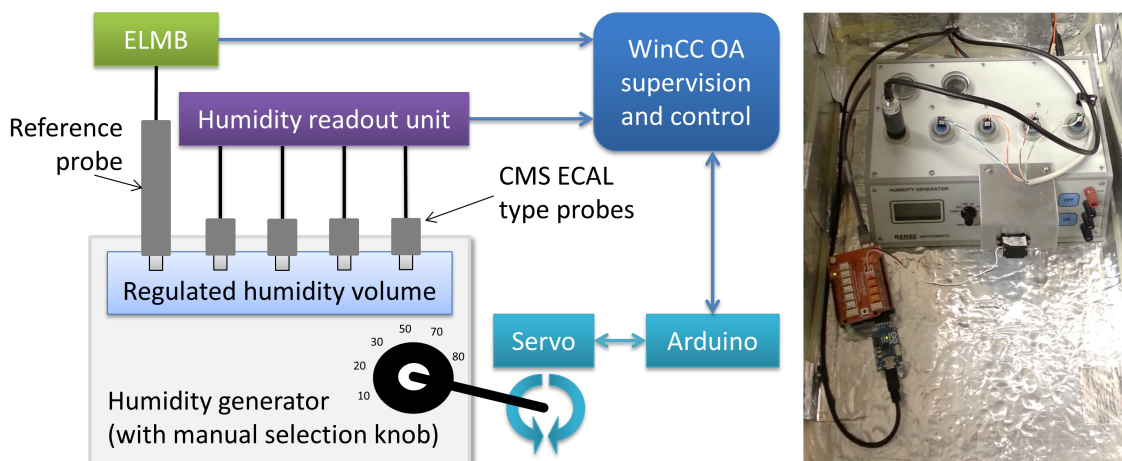


Figure 2. A schematic and photograph of the humidity readout calibration setup.

SIMATIC WinCC Open Architecture (WinCC OA) from ETM professional control [6] was used to monitor all humidity probes and to read the temperature from the reference probe. Additionally, WinCC OA was used to control the humidity generator via the Arduino controller and to automate the calibration sequences. The data from the calibration were stored in the WinCC OA archive for analysis. Each calibration sequence involved stepping through relative humidities of 10%, 20%, 30%, 50%, 70% and 80%, with several hours to stabilise at each humidity level before capturing data.

2.2.2. EB and EE humidity readout deployment. Following the calibration of the humidity readout system, it was deployed in CMS. The supervision software was updated to include readout of this hardware and to provide the precisely calibrated conversion between ADC and humidity values using a 4th order polynomial. A correction for probe temperature was also implemented, based on the temperature readings from PTM. This enables, for the first time, to monitor the low humidity values that are typically present in the detector. The system is being closely monitored to validate that it is robust as well as to understand the patterns and variations in the data that are now visible (figure 3).

Further work is planned to more closely integrate the humidity data into the DCS software layer, such as the generation of alarms when humidity values exceed given thresholds.

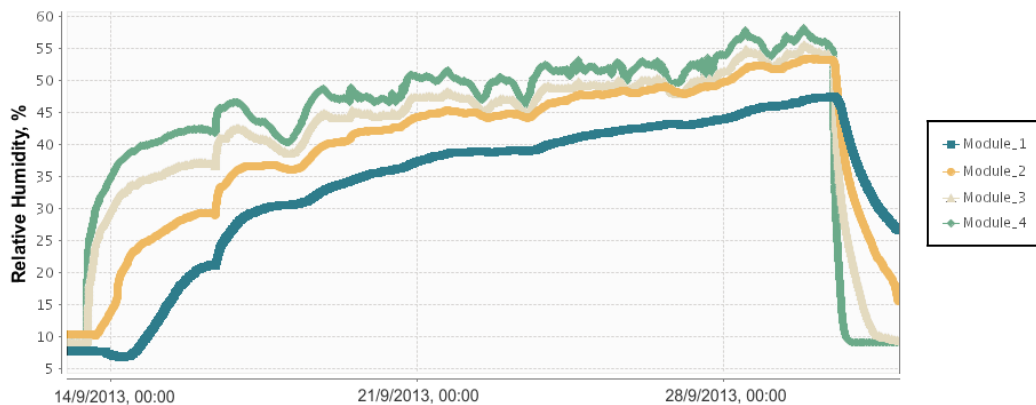


Figure 3. An example of humidity data in a region of EB. The overall rise of humidity is due to the suppression of nitrogen gas flow. The sharp fall correlates with activities on a neighbouring detector.

2.3. Preshower bias voltage (ES BV) monitoring

The ES BV distribution and monitoring boards were recently upgraded [7] to provide more flexible distribution of power supply channels to the silicon sensors in the detector. An additional feature of this new distribution system is to provide ELMB-based monitoring of the currents in each of the distributed channels. Following the successful deployment of these boards, a detailed study is underway to characterise and calibrate the values measured by the ELMBs.

3. Software consolidation

The software of the CMS ECAL DCS is built with the WinCC OA supervisory control toolkit. As the software already implements all required functionality to efficiently control and monitor the detector, efforts have been focussed on producing a clean and easily maintainable code base [8].

3.1. Merged software architecture

The software applications of the CMS ECAL DCS were initially developed to run on independent hosts. The possibility of running the applications side by side on the same server was not originally considered. More powerful computers are now available and the DCS software load can be concentrated on fewer machines, reducing the amount of rack space used by the DCS servers as well as reducing the cost of the server hardware. To achieve these goals, it was necessary to identify and remove all incompatibilities between the software applications.

The compatibility issues involved non-unique resource names in the DCS applications. Conflicts with the naming of persistent data objects, re-use of WinCC OA process numbers and multiple declarations of CAN bus identifiers were the most common problems. Due to the existing application design and the low-level of these compatibility issues, the solutions often involved significant changes to the software. Many secondary effects arose, such as the additional effort required to preserve the integrity of the historical data record when changing the data object names.

Once the applications were modified and tested, it was possible to choose the best merging scheme in order to evenly distribute the processing load, memory consumption and complexity related to I/O

interfacing. These decisions were taken based on the experience and knowledge gained of operating the DCS over the past years. However, a period of validation in the production environment is still required to verify the assumptions and estimations made when selecting the merged architecture.

4. Current status and plans

Since the beginning of LS1 in February 2013, the 24/7 support service provided for the CMS ECAL DCS has been suspended whenever the detector and supporting equipment is switched off for long periods of time. A basic level of support is offered to ensure uninterrupted monitoring of environmental conditions in the detector and to support brief periods of detector powering when other CMS ECAL systems are being tested. This reduced support load has enabled significant progress to be made in terms of the upgrades described in previous sections.

Following the successful deployment of the PTM and humidity upgrades, further detailed studies of the ES BV distribution board behaviour will now be the focus of activities. The consolidated DCS software has been deployed on the new host servers and basic functional testing has been performed. A full scale test to validate the software in normal operating conditions is planned and will be performed when all elements of the DCS can be powered on simultaneously.

As LS1 continues and comes to an end, it will be necessary to return to the 24/7 support service in order to ensure that the DCS can maintain the CMS ECAL in the operational state required to enable other detector development activities.

5. Conclusion

LS1 has provided an opportunity to deploy significant upgrades to the CMS ECAL DCS. With an improved power distribution for the PTM, this system will be more robust to failure as it ages over the next years of LHC physics data taking. The upgraded humidity readout system is providing insights into the detector volume environment that have previously been unobservable. This provides new opportunities to use this information to allow better detection and reaction to abnormal situations. The DCS software has been consolidated and merged to run on new host server hardware. The new servers will provide a robust platform for the DCS software over the next years, contributing to the high level of availability of the CMS ECAL DCS that will be required to ensure a successful data taking campaign when LHC restarts.

Acknowledgements

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