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# Maintaining and improving the control and safety systems for the Electromagnetic Calorimeter of the CMS experiment

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# Maintaining and improving the control and safety systems for the Electromagnetic Calorimeter of the CMS experiment

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**Abstract**. This paper presents the current architecture of the control and safety systems designed and implemented for the Electromagnetic Calorimeter (ECAL) of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC). An evaluation of system performance during all CMS physics data taking periods is reported, with emphasis on how software and hardware solutions are used to overcome limitations, whilst maintaining and improving reliability and robustness. The outcomes of the CMS ECAL Detector Control System (DCS) Software Analysis Project were a fundamental step towards the integration of all control system applications and the consequent piece-by-piece software improvements allowed a smooth transition to the latest revision of the system. The ongoing task of keeping the system in-line with new hardware technologies and software platforms specified by the CMS DCS Group is discussed. The structure of the comprehensive support service with detailed incident logging is presented in addition to a complete test setup for reproducing failures and for testing solutions prior to deployment into production. A correlation between the acquired experience, the development of new software tools and a reduction in the DCS support load is highlighted.

## 1. Introduction

The control and safety systems implemented for the Barrel (EB), Endcaps (EE) and Preshower (ES) partitions of the Compact Muon Solenoid (CMS) Electromagnetic Calorimeter (ECAL) [1] have reached a mature state. Both systems have proven to be extremely robust, operating for the past four years without interruption. This has included long periods of physics data-taking interspersed with technical stops, during which several improvements were made based upon running experience. Nevertheless, as hardware devices and software platforms evolve, the need to provide long-term support for both systems makes it mandatory to keep them in-line with the new technologies. As the safety systems have a solid base on SIEMENS industrial control hardware with Mean Time Between Failures (MTBF) of over 8 years for all modules and consolidated Programmable Logical Controllers (PLC) [2] code, this paper will focus on the Detector Control System (DCS) [3][4], which needs considerably more attention in respect of mid- to short-term upgrades, in order to be kept in an easily maintainable state.

## 2. The control and safety systems architectures

This section presents the current control and safety layouts, their connections to other subsystems and respective data flows.

### 2.1. The Detector Control System

The system comprises the complete controls software for all ECAL partitions and the hardware for:

- interfacing the EB/EE low voltage power supplies to the DCS computers;
- interfacing the monitoring systems listed below to the DCS computers;
- monitoring the temperature of the EB/EE crystals region;
- monitoring the EB/EE relative humidity;
- monitoring the EE/ES bias currents.

Developed in the Supervisory Control and Data Acquisition (SCADA) platform ETM/SIEMENS Simatic WinCC Open Architecture [5] (formerly PVSS) and with wide use of the Joint COntrols Project (JCOP) [6] and CMS DCS [7][8] frameworks, the CMS ECAL DCS software components, historically fractioned according to subsystems and hardware limitations, have undergone major changes over the past two years. Figure 1 presents a simplified diagram of the current software architecture and external data flows. The evolution from the previous reported configuration [3][4] to the actual state, as well as the ongoing and foreseen tasks associated with the migration to the new computer architecture are discussed in more details in the following sections.

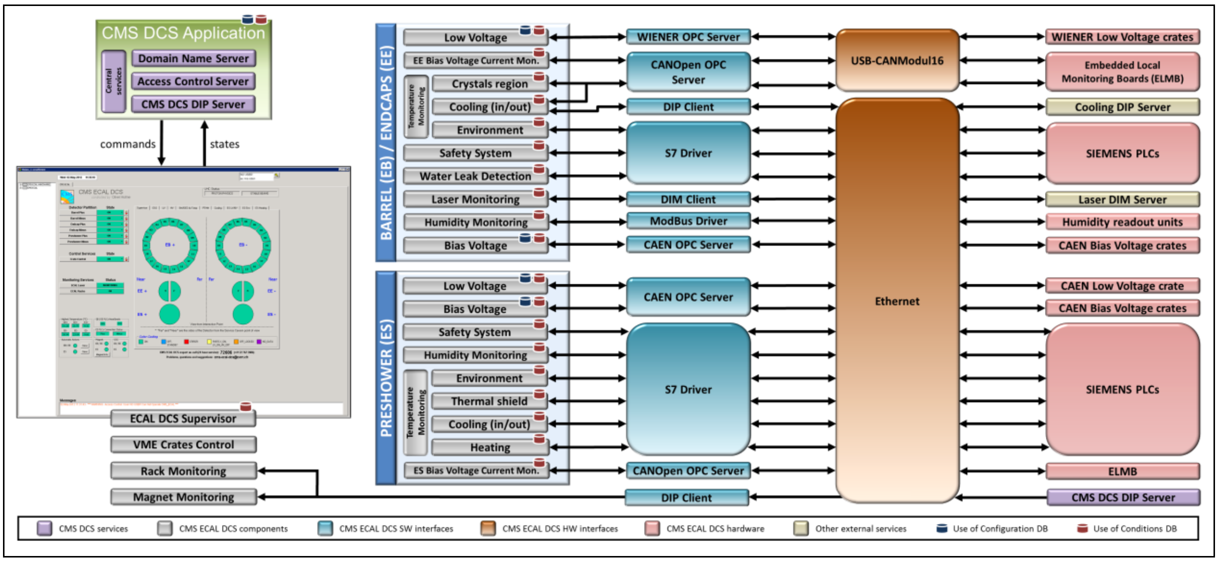

Figure 1. The CMS ECAL DCS Architecture [3][4]

### 2.2. The Detector Safety Systems

From the original design, the SIEMENS PLC-based safety systems for the EB/EE and ES are completely decoupled. While the former features a dual, fully redundant, configuration with readout and interlock units designed and produced by the CMS Belgrade Group, the latter shares the same code basis and non-redundant hardware architecture as the CMS Tracker Safety System [9] and provides one dedicated configuration for each ES endcap.

Both systems have hardwired connections to the CMS Detector Safety System (DSS) and to their respective Detector Cooling PLCs, being able to trigger and to receive interlock signals in case the safety of one or more partitions is compromised. In addition, hardwired interlocks from the CMS Magnet Control System (MCS) trigger the shutdown of the entire ECAL in the case of a CMS solenoid ramp.

Even with consolidated code fulfilling the current safety requirements, the interlock granularity and the use of internal diagnostic routines for triggering alarms through the DCS software should be re-evaluated. This could lead not only to significant improvements to the system functionality, but also to ease the uncovering of hardware issues.

The EB/EE safety system monitors the on-detector air temperature and water leak sensors. Due to the need of guaranteeing their data integrity at all times, the connection between the PLCs and the readout units is monitored and interlocks to the powering systems are set in case of communication problems. In addition to the CMS DSS off-detector protections, signals based on critical hazards, such as water leaks inside the low voltage racks and lack of cooling water flow for the low voltage power supplies are used to trigger interlock signals to protect the concerned equipment. The ES safety system monitors the air/cooling/heater temperatures and dew points inside the ES and relies on the CMS DSS for the off-detector safety actions.

Figure 2 illustrates a simplified block diagram of inputs and interlocks for both systems.

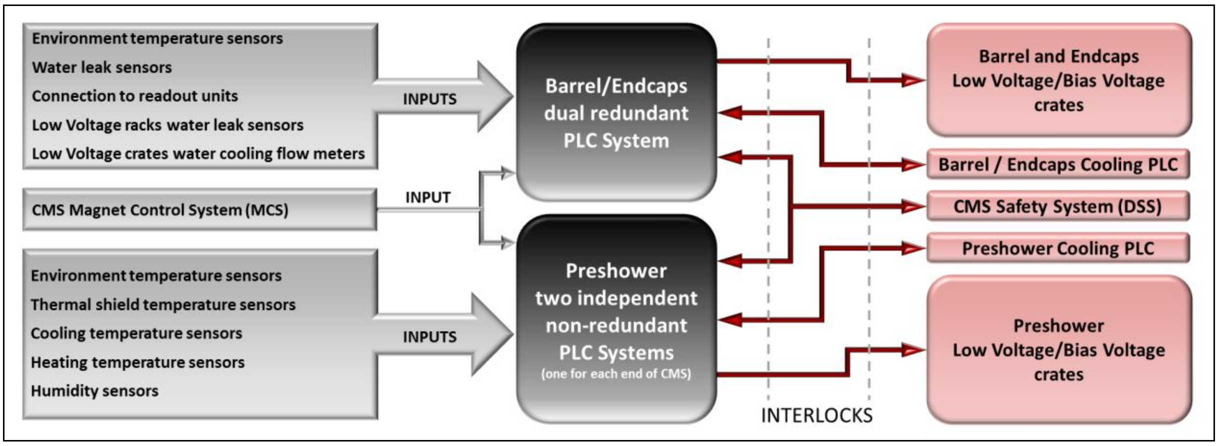

Figure 2. The CMS ECAL Safety System Architecture

## 3. Software Development

Over the past two years considerable efforts were made to optimize the control system code structure, as demonstrated by a significant reduction in both code quantity and duplication (Figure 3). Historically fragmented in several components with different solutions for similar mechanisms, the software underwent a complete analysis [3] in 2010 envisaging a process of smooth homogenization towards a cleaner, easily maintainable and robust configuration, while keeping and improving the existing functionalities.

All applications are going through several merging processes, at all levels, in order to profit at maximum from the extended hardware resources and software platforms that are now available, discussed in detail in section 4.1. Individual configuration databases were merged into one, containing the relevant parameters for all DCS components installation and runtime hardware configuration. A similar step is foreseen for the conditions data archiving.

The next and ultimate step towards this system optimization is to group applications onto fewer computers according to functionality and software interface needs. A clear example of such a procedure is presented by Figure 4, where all components related to CAEN crates are combined into a single and homogeneous application.

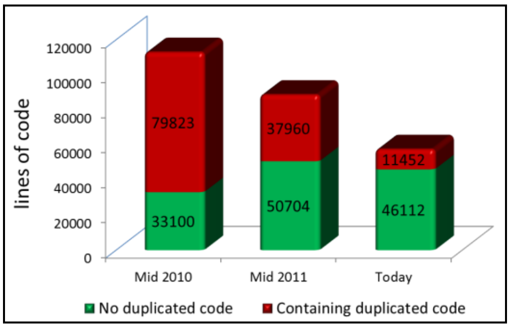

Figure 3. The CMS ECAL DCS code reduction

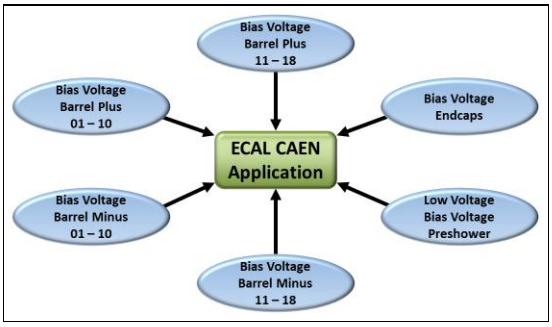

Figure 4. Example of applications merging

To minimize the impacts of the software evolution and to guarantee easy rollback procedures, a piece-by-piece approach was successfully adopted, allowing transitions to new configurations throughout the years, during the short periods of LHC technical stops.

## 4. The CMS ECAL DCS Evolution

As software platforms and hardware technologies evolve, it becomes mandatory to keep the control system in-line with the new solutions. The running experience becomes a key factor for understanding possible ways of improving the existing system, as well as for extending its functionality. This section presents the four major ongoing tasks towards an enhanced system configuration.

### 4.1. New generation of computers and software platforms

Originally designed to run with software components scattered across 15 rack-mountable computers (1U PE1950 and 2U PE2950) running Windows XP and PVSS3.x versions, the migration to a small set of powerful DELL M610 blade servers running Windows 7 and newer WinCC OA versions introduces a set of complex challenges to be overcome prior to their installation in the CMS environment.

It is mandatory not only to certify all software interfaces (drivers, OPC servers, etc) in the new environment, but also to acquire guarantees of their further development and long-term support. Concerning unexpected issues faced so far, a good example is related to the WinCC OA licenses which are generated according to unique codes, based on the computer hardware configuration. After detailed investigation in partnership with the ALICE DCS and CERN Industrial Controls & Engineering (EN/ICE) groups, it was found that after a server restart, it may happen that the application detects the same Windows 7 hardware configuration as being different due to changes in the virtual network interfaces. As none of these interfaces are used by our system, the problem is easily fixed by their removal.

### 4.2. Evolution of hardware interfaces

Over the past two years, the Controller Area Network (CAN) interfaces between the DCS computers and the EB/EE low voltage power supplies and the Embedded Local Monitoring Board (ELMB)-based monitoring hardware followed very smooth transitions to comply with the new requirements.

At first, all internal KVASER PCIcanx 4*HS cards were systematically replaced by SYSTEC CAN-USBModul16 adapters in order to guarantee, in case of a computer failure, a quick replacement without the need to install the PCI card inside or of keeping spare computers in a non-standard configuration. The second and current step of this evolution was driven by the approach of running the SCADA projects in a redundant mode, with one host in the CMS Underground Service Cavern (USC) and the other in the datacenter at the surface level. To accomplish this new design it is mandatory to establish all hardware connections through ethernet, therefore adapters for communication with the CAN hardware are required. The device chosen for this task is the DIGI AnywhereUSB/14 and it is currently under evaluation in our laboratory facilities. A complete timeline of the described evolution is presented by Figure 5.

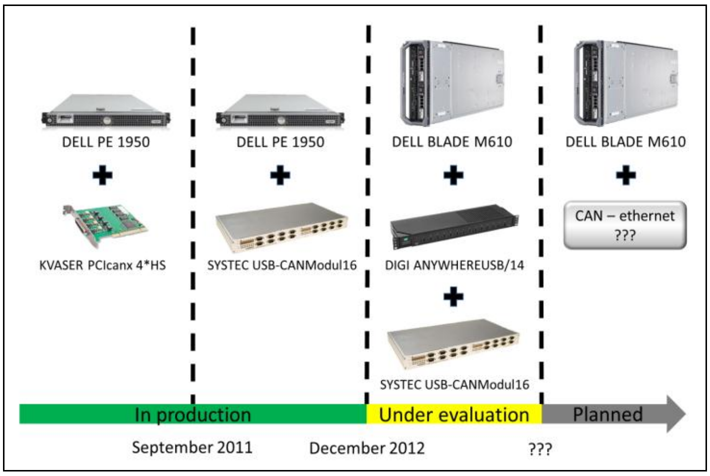

Figure 5. Example of hardware interface evolution

In accordance with the redundancy requirement, the design for the upgrade of the CMS ECAL Relative Humidity Monitoring System (RHMS), discussed in details in the next section, already included the ADFWeb HD67507 RS485-ethernet MODBUS adapters, which were extensively tested in our laboratory and fulfil the system requirements.

As all hardware changes require very careful evaluation and proper certification at the CMS environment, the complete configuration is scheduled to be deployed during the first LHC Long Shutdown (LS1), starting in spring of 2013.

### 4.3. The Relative Humidity Monitoring Hardware Upgrade

The constraints on the relative humidity readout range imposed by the capacitance of the long cabling between the readout electronics and the humidity sensors installed inside the CMS ECAL EB/EE motivated the design and the development of a device to provide extremely low frequency excitation and very good resolution within the extended humidity range of 10 – 80%.

The readout units were designed and produced by the CMS Belgrade Group in collaboration with the CMS ECAL DCS Group, following the MODBUS protocol specification to ease the interface to the control system software through the MODBUS-TCP driver already available in WinCC OA.

In 2011, one unit was installed in the CMS experimental cavern and connected to four humidity sensors for evaluation. Due to the impossibility of laying down new cables between the CMS USC and the Underground Experimental Cavern (UXC) before the yearly shutdown, the Precision Temperature Monitoring (PTM) System, which by design has two CAN buses, was re-configured to use a single bus, allowing one of its cables to be used for this initial evaluation. Even with the unit not being calibrated, during this period it presented reasonable values within the expected range.

To read out the 160 humidity probes installed inside the barrel (144) and endcaps (16), four units of 48 channels each will replace the existing hardware in the UXC. Due to the complexity of their design, each channel requires individual calibration. This procedure is ongoing and consists of two steps:

- Calibration of a group of four humidity sensors against a certified reference probe;
- Individual calibration of readout channels, in groups of four, using a setup that combines a humidity generator and a set of salts with known and precise humidity values.

A schematic diagram detailing the upgrade is presented in Figure 6.

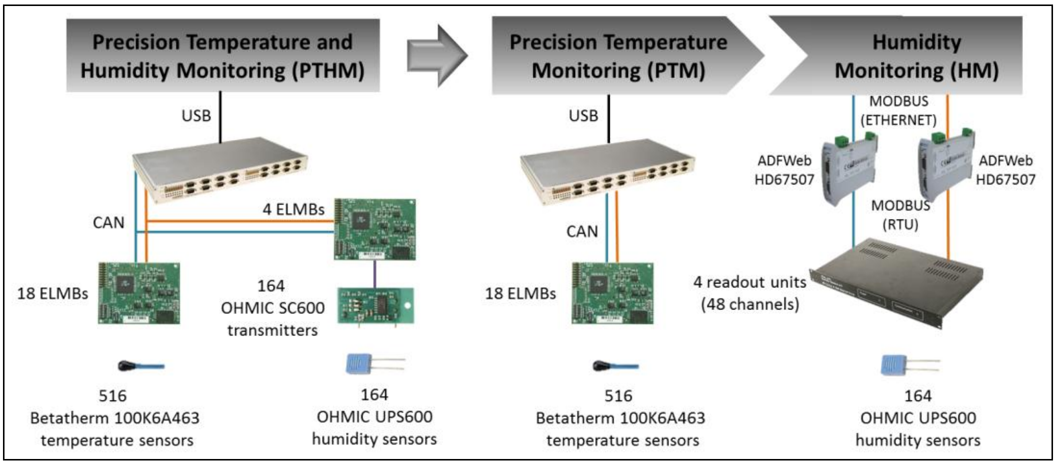

Figure 6. Upgrade of the EB/EE humidity monitoring system

### 4.4. Preshower Bias Voltage currents monitoring

Motivated by the need to increase the bias voltage distribution granularity, to detect and understand individual sources of bias current increases and possibly to study their behaviour, a new patch panel based on a flexible power distribution matrix with individual lines to either pairs or single Preshower sensors was designed and implemented by the CMS Preshower Group, with significant collaboration of the CMS ECAL DCS Group. Each of the 16 patch panels is equipped with 5 ELMBs, capable of monitoring all bias currents to the detector.

In order to optimize the CAN load and to introduce some granularity in case of single failures, the 80 ELMBs were distributed in four buses and interfaced to the control system via the available SYSTEC USB-CANModul16 devices. For each bus, a 12V power supply triplet is provided to match the granularity introduced by the CAN buses.

The basic software structure is deployed and has been running since February 2012, archiving all individual currents on significant changes and predefined periods to the Conditions Database. The data can be easily retrieved using the standard CMS DCS plotting tool available at their web portal [8]. WinCC OA panels are still under development and will soon be available through the CMS ECAL DCS application.

For an optimal absolute accuracy, further verification and calibration of the readout at our laboratory facilities is required and will be performed systematically along 2012 and finalized during the LHC LS1.

## 5. The CMS ECAL DCS Support

The DCS support to the detector operations is provided on a 24/7 basis and organized in two well defined services. The first, called CMS ECAL DCS Operator On-Call, is responsible for the direct support to daily operations, such as powering on and off detector partitions and moving the detector to safe states in case of potential problems. The second and ultimate service, called CMS ECAL DCS Expert On-Call, relies on a pool of experts with full access to the system and advanced skills for handling abnormal conditions and more complex failures, including hardware related issues.

Since the second half of 2010, an incident logging system was implemented for both services, allowing the experts to spot and correct weaknesses of the system and to evaluate areas to be improved. The success of this system is clearly seen by the reduction of the average of support calls from over 30 to less than 10, during periods of two weeks.

A laboratory equipped with a set of computers running the full ECAL DCS software and all existing hardware interfaces, always in-line with the system at CMS, and a complete system in smaller scale for supporting a spare Supermodule (SM) [1] are constantly used for reproducing problems and for further development of the control system. Furthermore, any required upgrade is exhaustively tested in these facilities prior to the deployment into the CMS environment.

## 6. Conclusion

The ECAL safety systems are based on very solid hardware configurations with extremely long life cycles, avoiding the need for short- to mid-term upgrades. In respect to the PLC codes, there is still room for non-critical improvements and new features, which could be considered during the LHC long shutdown periods. The planning for the coming years should focus on preventive maintenance, periodic health checks and systematic routine tests. The control system provides excellent support and additional protection for the detector operation. While reaching a consolidation phase, it faces several challenges to be kept in-line not only with the new CMS DCS standards, but also to follow the natural evolution of hardware interfaces and software platforms. In addition, new solutions are available and under implementation to overcome existing hardware limitations and to improve the provided services.

## 7. Acknowledgements

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