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The LHC Compact Muon Solenoid experiment Detector Control System

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Abstract. The Compact Muon Solenoid (CMS) experiment at CERN is a multi-purpose experiment designed to exploit the physics of proton-proton collisions at the Large Hadron Collider collision energy (14TeV at centre of mass) over the full range of expected luminosities (up to $10^{34}cm^{-2}s^{-1}$). The CMS detector control system (DCS) ensures a safe, correct and efficient operation of the detector so that high quality physics data can be recorded. The system is also required to operate the detector with a small crew of experts who can take care of the maintenance of its software and hardware infrastructure. The subsystems size sum up to more than a million parameters that need to be supervised by the DCS. A cluster of roughly 100 servers is used to provide the required processing resources. A scalable approach has been chosen factorizing the DCS system as much as possible. CMS DCS has made clear a division between its computing resources and functionality by creating a computing framework allowing plugging in of functional components. DCS components are developed by the subsystems expert groups while the computing infrastructure is developed centrally. To ensure the correct operation of the detector, DCS organizes the communication between the accelerator and the experiment systems making sure that the detector is in a safe state during hazardous situations and is fully operational when stable conditions are present. This paper describes the current status of the CMS DCS focusing on operational aspects and the role of DCS in this communication.

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1. Introduction

CMS experiment [1] has ~10^8 readout physics data acquisition channels distributed in a tracker, a calorimeter and a muon detection system. The tracker system is made of an inner silicon pixel sub-detector surrounded by a silicon strips one. An electromagnetic scintillating calorimeter, complemented with a silicon preshower detector encloses the tracker system. A hadronic sampling calorimeter, around the electromagnetic calorimeter, sits inside a 6m diameter and 13m long solenoidal 4T magnet. Beyond the magnet, an iron return yoke is filled up with a compact structure of muon cathode strips, resistive plates and drift tubes chambers. CMS data acquisition (DAQ) [2] and trigger system selects the most interesting physics events. From the LHC 40MHz full beam crossing frequency (a beam cross every 25ns), that at design luminosity yields ~1MB of zero-suppressed data, the system selects events at 10^2Hz. One of the main DCS responsibilities is ensuring that the bias voltages are present in the front end electronics and detector components so that high quality physics data can be recorded by the DAQ. It should guarantee, at the same time, a safe detector operation. A last resort, PLC based detector safety system (DSS) prevents any critical damage to the experiment electronics. Like other experiment systems, DCS should contribute as much as possible to improve the detector efficiency so that, from the luminosity delivered from the accelerator, CMS can record as much data as possible.

2. Control system overview

2.1. Requirements and responsibilities

The detector control system is required to run on a 24h/day and 365d/year basis. It should always guarantee a safe and efficient detector operation. The safe operation is ensured by:

- Anticipating any safety system (PLC based hardware system) action, by activating protection mechanisms whenever adverse conditions are detected (for example: high temperatures, high humidity, water leaks, electrical trips...)
- Preventing any operator or automatic mechanism to perform potentially dangerous actions
- Issuing alert notifications

To anticipate the Detector Safety System (DSS) the DCS sets lower reaction activation thresholds. There are mainly two reasons why it is desirable to act before the experiment DSS. First, safety hardwired actions are usually more radical and have bigger hardware granularity while DCS actions have smaller granularity. Second, there are situations where the conditions might not imminently damage the hardware (for example, hardware working on the limits of the operating temperature range) but they speed up its aging. In these situations, DSS actions are not appropriate as abruptly cutting the power on the source lines can produce the same or worse effects than the mentioned aging conditions. DCS can smoothly lower voltages until hazardous conditions disappear.

The DCS provides different means to switch on/off bias voltages. The voltage setting can be modified by a user from remote interfaces as well as from CMS control room DCS operator station. It can also be automatically commanded according to programmed logic. In order to avoid sending commands in potentially dangerous situations, a DCS protection system has being provided with the knowledge and means to block them at the lowest software level. For instance, there are parts of the detector that should not be turn on while the experiment magnet is ramping and other parts which must be off or lower their voltages while particles are being injected in the accelerator. This protection system not only blocks commands but also makes sure that the hardware settings are the correct ones depending on activating condition.

The DCS can issue different sort of notifications when alerts are triggered in the system. An SMS notification system warns experts of alerts in their sub-systems. Also, a global DCS alert screen

notifies the control room operator of any relevant alert triggered. These alerts are filtered and sent to a voice notification system that informs the control room crew about the most important events. While assuring a safe operation providing the necessary software interlocks, DCS should provide an efficient detector operation. The DCS does this by:

- Making sure that all bias voltages are present as soon as the accelerator beam conditions allow for physics data taking
- Guaranteeing that the controlled parameters are stable within their calibrated operating ranges

The DCS parameters should be closely monitored as the detector performance does depend in some cases in the stability of these parameters. As an example, the electromagnetic calorimeter momentum resolution for high energy photons depends on the gain of the readout avalanche photodiodes that vary with the temperature like $-2\%/°C$. To achieve a better resolution than the 0.5% constant term that dominates in this energy regime the calorimeter needs to keep the temperature stable within $0.05°C$

2.2. Control system size

The DCS accounts for ~1M parameters that need to be constantly monitored. The parameters are not only monitored but their changes activate analysis, smoothing, alert and archiving mechanisms that in some cases are followed by automatic actions. A considerable amount of these parameters, mainly voltage settings, are not only monitored but are also set by DCS. The system is distributed across a farm of approximately 100 servers and it is based in PVSS [3] product from ETM Company. A summary is given in Table 1.

Table 1. The detector control system size in terms of monitored parameters

System Name	Number of PCs	Monitored Parameters	Controlled Parameters
Tracker	14	350k	20k
Calorimeter	14	115k	2k
Muon	30	435k	30k
Trigger	2	1k	0.5k
Alignment	3	3k	0.5k
Services	35	20k	1k
Total	**98**	**934k**	**34k**

2.3. Design and implementation

The DCS building blocks are made out five parts belonging to different layers. The structure of these layers is summarized in figure 1.

The first layer is the hardware layer. The experiment control system hardware is mainly based on industrial solutions. CAEN and WIENER power supplies are used as voltage sources. Embedded Local Monitored Boards (ELMBs) [4], made by CERN, are used for the readout of thousands of sensors. In addition to this hardware, many other industrial solutions are used for flow readings, alignment monitoring, environment conditions monitoring such as temperature, pressure or humidity, etc. Still, when industrial solutions did not fit the sub-detectors requirements, custom solutions were implemented. As an example, custom power supplies are used by some detector partitions.

Next layer is the driver layer. For the DCS hardware readout a set of industrial and custom drivers are used. OPC is one of the most commonly used for the readout of the industrial power supplies and

ELMBs. Other drivers like Siemens S7, SNMP or CERN custom DIP/DIM are also widely used across the system.

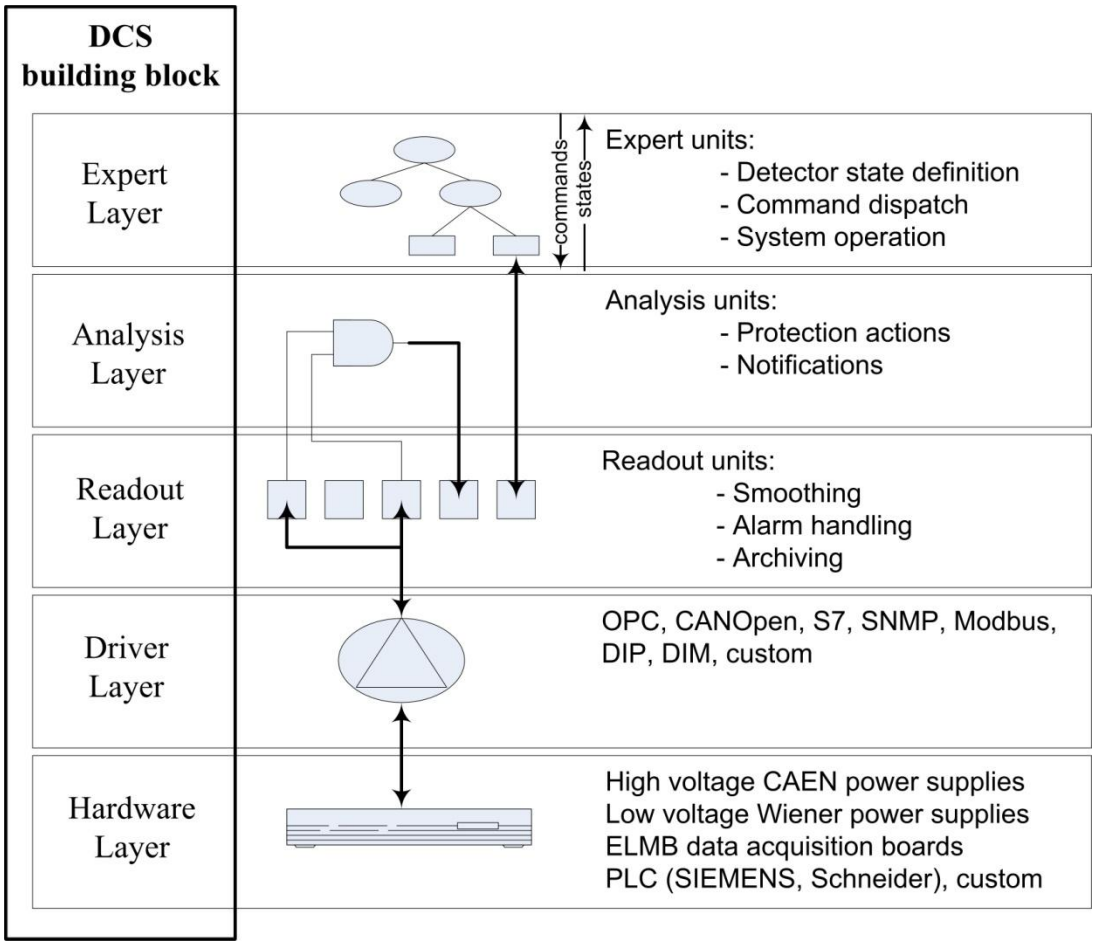

Figure 1. A Detector Control System building block

In the third or readout layer, readout units mainly perform three tasks:

- Smoothing the values read from the drivers so not all changes within a defined range activate analysis scripts or other automatic mechanisms
- Handling alerts when the values exceed defined thresholds limits
- Filtering with different types of parameter function in order to decide when to archive them to a relational conditions database for later analysis

The readout units (called in PVSS SCADA datapoints) are used as the input by the analysis layer. Information coming from different hardware is put together here generating global conditions that can be again output to readout units or used to trigger automatic actions. In this layer reside mechanisms like the one dedicated to protect the detector or the one issuing SMS notification to experts. Finally on the top there is the expert layer. Here the detector is modelled with a set of expert finite state machine units. These units are based on a CERN Joint Controls framework development called Finite State Machine (FSM) toolkit that wraps the State Machine Interface (SMI++) [5] framework. The expert units are arranged in a hierarchical tree-like structure (figure 2) where the states are summarized upwards using expert system like rules while commands are flowing downwards.

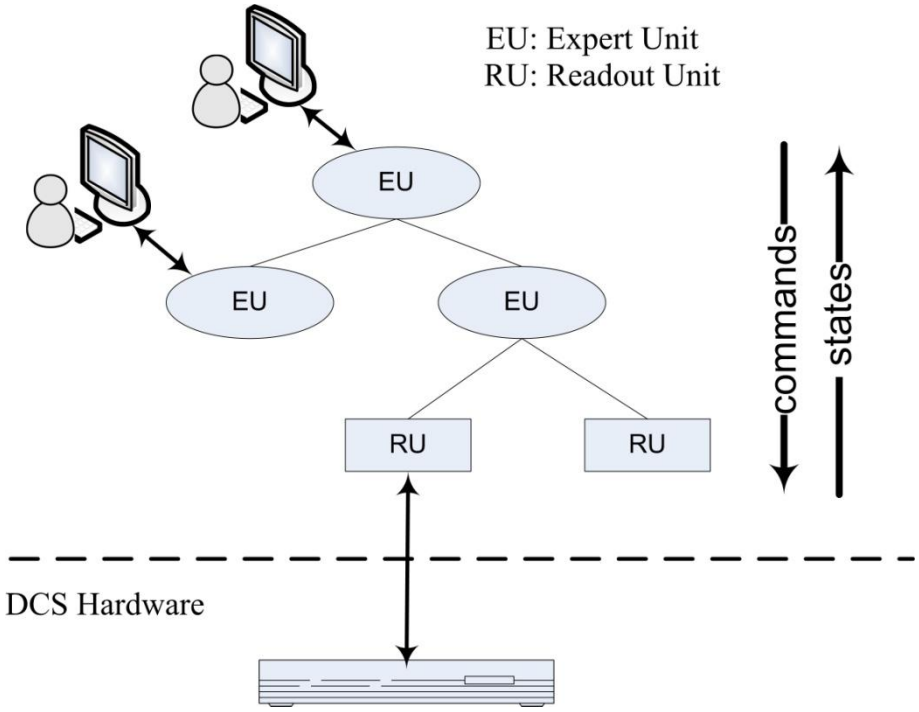

Figure 2. The expert system layer tree like hierarchy

2.4. The computing resources, system functionality and software life cycle

CMS has introduced in its control system design a model that allows for a complete separation between the production and the development system. As opposed to the traditional approach where engineering developers provide complete Supervisory Control and Data Acquisition (SCADA) projects that are integrated into a distributed system, in CMS developers are requested to extract the functionality from their SCADA projects in the form of functional plug-in components that they upload into a central DCS repository. These plug-in components are then distributed across the production SCADA projects according to a configuration database populated by control system administrators. This approach allows for versioning, load balancing and automatic recovery after PC failures. A collection of web based applications are used to monitor SCADA project processes as well as to upgrade or roll back functional component versions. The system architecture was designed centrally [6] and sub-detector developers where provided with development and integration guidelines.

3. Control system automation

In order to maximize the DCS efficiency and to simplify the detector operation the reactions of the detector to the machine conditions have been automated. There are two types of automated actions. Protection actions, acting at the level of the readout and driver layers are activated to prevent harmful situations. These actions have priority over any other in the system. They set the hardware to predefined states and they lock it so that nothing can change those settings until the protection triggering condition has cleared out. The second type of actions are the standard control actions. These are forwarded to the detector through the finite state machine based control tree that takes care of dispatching them to the low level hardware devices according to the programmed logical rules and partitioning states.

An automation matrix, stored in a configuration database, defines the protection and standard control actions for all the LHC machine modes (proton physics, ion physics, calibration...) and beam modes

(beam setup, beam injection, ramping...) combinations. Every time the LHC changes its operation mode CMS partitions automatically react in accordance to what it is defined in this database. Sub-detectors have the responsibility of keeping up to date their matrix entries. A web based application accessible by the whole collaboration can be used to inspect the programmed DCS automatic actions giving a general overview of the detector behaviour.

4. Control system operation

Since the start of LHC collisions DCS provided an interface allowing a single operator to control the whole experiment DCS hardware. DCS operators follow a 2 hours introduction course and are not required to have any control system knowledge in advance. In most cases, the automation system takes cares of issuing any needed command during operation. The main role of the operator is to follow this operation and to warn on-call experts when unexpected situations occur. A simple interface is provided to the operators. A main supervisor screen provides information on the main detector partitions status allowing monitoring the automatic actions and LHC mode changes. A second screen summarizes the experiment alerts providing instructions to the operators on which expert to call and where and how to perform further checks if needed. Support panels [7] for sub-detectors and global services are also provided for complementary information.

5. Summary

The robust system architecture has proven to ensure the safety of the detector. The automation actions mechanisms are providing the system with efficiency above 96% for all physics runs. The number of on call expert interventions is very small and operators are able to deal with most of the DCS incidents with the interface provided in the control room. The main development force in the control systems is now driven in two directions. First, to make redundant all the control sub-systems in terms of computing hardware and software in order to eliminate any possible down time due to PC failures. And second, to homogenize the system code and sub-detector architecture as much as possible to ease long term system maintenance. A DCS homogenization project is ongoing. Studies to identify similar functionality across sub-detectors are in progress. The aim is to replace the existing sub-detector components by common centrally supported versions. Some common functional components are already being developed. The goal is to deploy them during the long LHC shutdown period in 2012-2013.

Acknowledgments

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