THE DETECTOR CONTROL SYSTEM FOR THE ELECTROMAGNETIC CALORIMETER OF THE CMS EXPERIMENT AT LHC

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Abstract

In this paper we describe the main design objectives, the detailed specifications and the final layout of the Detector Control System (DCS) for the electromagnetic calorimeter (ECAL) of the CMS experiment. Emphasis is put on the system implementation and specific hardware and software solutions in each of its sub-systems. The latest results from the tests of final prototypes of these subsystems during the 2006 ECAL test-beam programme, as well as the installation and commissioning of the whole DCS at the CMS construction site are discussed.

INTRODUCTION

The Compact Muon Solenoid (CMS) experiment is one of the two large multi-purpose detectors at CERN's Large Hadron Collider (LHC) [1]. CMS is presently in the final phase of construction work at Point 5 near Cessy (France). One of the most accurate, distinctive and important detector systems of the CMS experiment is the high precision Electromagnetic Calorimeter (ECAL). It will provide measurements of electrons and photons with an excellent energy resolution and thus will be essential in the search for new physics, in particular for the postulated Higgs boson.

In order to successfully achieve these physics goals the ECAL collaboration has designed the calorimeter as a homogeneous hermetic detector based on 75848 Lead-tungstate ($PbWO_4$) scintillating crystals. Avalanche photo diodes (APD) and vacuum phototriodes (VPT) are used as photodetectors in the barrel part and in the end-cap parts of the detector, respectively [2]. However, the light yield of $PbWO_4$ crystals and the amplification of the APDs are rather sensitive to temperature and bias voltage fluctuations [3, 4]. Therefore, the use of these components has directly imposed challenging constraints on the design of the ECAL, such as the need for rigorous temperature and high voltage stability. At the same time, mechanisms that allow radiation to induce changes in crystal transparency imposed additional requirements for "in situ" monitoring of the crystal transparency [2]. For all these reasons specific ECAL sub-systems that provide the necessary services had to be designed. These include: Cooling system [5], High Voltage (HV) and Low Voltage (LV) systems [6,7], as well as Laser Monitoring system [8]. In addition, a sophisticated ECAL Detector Control System (DCS) that could provide the necessary control and monitoring of the proper functioning of all these sub-systems, as well as the control and monitoring of important ECAL working parameters, had to be designed.

DESIGN OF THE ECAL DCS

The ECAL DCS [9] has been designed to provide several functionalities. Its first functionality is the autonomous monitoring of the detector environmental parameters, such as the temperature of the thermal shield of ECAL crystals and APDs, the temperature and humidity of the air inside the electronics compartments of Supermodules (SM), and the presence of water leakage inside the SMs. Its second functionality is the monitoring of the running conditions of on-detector electronics (APD leakage currents and bias voltages), as well as the monitoring and control of all ECAL subsystems (HV, LV, Cooling and Laser monitoring systems). The third functionality of the system is to provide early detection of abnormal conditions, issue appropriate warnings and alarms, execute control actions and trigger hard-wired interlocks to protect the detector from severe damage.

Parts of these DCS functionalities are implemented through software applications running on dedicated DCS computers, as is the case with the HV, LV, Cooling and Laser monitoring systems. These applications communicate to hardware or to embedded computers using standard network or field-bus protocols.

In the case of the monitoring of on-detector electronics, specific detector parameters are collected by dedicated ASICs (Detector Control Units, DCUs) and read out via the control rings of the data acquisition (DAQ) system, before being transferred to the databases and to the DCS. These parameters include: temperatures near the APDs and VPTs, leakage currents of the APDs and the output voltages on the low voltage regulators.

The other part of the functionalities is implemented via dedicated DCS applications whose readout systems are completely independent from the ECAL DAQ. These are the ECAL Precision Temperature and Humidity Monitoring system (PTM/HM) and the ECAL Safety System (ESS). Detailed descriptions of sensors, readout electronics and communication protocols used by these systems are presented in the following sections.

PRECISION TEMPERATURE MONITORING AND HUMIDITY MONITORING (PTM/HM)

The purpose of the PTM system is to provide precision temperature measurements and to monitor the stability of the temperature distribution in the environment of the ECAL crystals and photo-detectors. In addition, it should provide archiving of the temperature history for use in the ECAL data processing.

In order to provide this functionality, 360 high quality NTC thermistors [10] are installed in the ECAL Supermodules and 80 more are to be installed in the ECAL End-cap Dees. Sensors are individually pre-calibrated by the manufacturer and then tested and sorted in the lab to ensure a relative precision better than 0.01 ºC.

The purpose of the HM system is to monitor the relative humidity (RH) of the air inside the electronics compartments and to provide warnings about potentially dangerous humidity conditions. There are 176 HM sensors with 5-7% RH precision [11] placed inside the ECAL. Both PTM and HM sensor samples were tested for their capability to work in an environment with high radiation levels and strong magnetic field that will be present in the ECAL region of CMS.

The readout systems of both PTM and HM systems are based on ELMB modules designed by the ATLAS experiment [12]. The ELMB module is a compact plug-on card with one embedded 16-bit ADC, one 64 channel analogue input multiplexer, one RISC microprocessor and one CAN bus interface. Each ELMB module is plugged on a specific PTM/HM electronic board that provides signal routing for 64 channels. In addition, PTM is using specifically designed circuit boards for thermistor excitation, while HM is using transmitters from the sensor manufacturer to excite the RH sensors.

The PTM/HM readout electronics is implemented on 6U-size boards that will be installed in four PTM/HM standard 6U Euro-crates. This configuration provides a readout system for 512 channels of the PTM and 192 channels of the HM system. The crates will be located on the balcony in the CMS experimental cavern (UXC), outside the CMS detector. The readout electronics has been successfully tested for the long-term operation in this environment [12].

The performance of the PTM readout system in terms of resolution and noise levels has proved to be outstanding. Temperature fluctuations from the noise introduced in the system are of the order of 0.001 ºC in the range of 18 - 22 ºC.

ECAL SAFETY SYSTEM (ESS)

The purpose of the ESS [13] is to monitor the air temperature of the ECAL electronics environment (expected to be in the range of 25 - 30 ºC), to monitor water leakage sensors routed inside the electronics compartments, to control the proper functioning of the ECAL Cooling and LV Cooling systems and to automatically perform pre-defined safety actions and generate interlocks in case of any alarm situation.

In order to achieve these goals 352 EPCOS NTC thermistors [14] are positioned in redundant pairs at the centre of each module of the ECAL barrel SMs and at four locations inside each quadrant of the ECAL End-cap Dees. In accordance with the design objectives, the ESS temperature sensors are calibrated to a precision of 0.1°C. The functionality of the water leakage detection has been based on commercial water leakage sensor-cables provided by RLE Technology [15].

The temperature and water leakage sensors of the ESS are read out by the front-end part of the readout system, which comprises 12 ESS Readout Units (RU) located in the CMS experimental cavern. Each ESS RU represents an electrically and logically independent entity that can support up to four SMs or up to two End-cap Dees.

In order to provide a reliable and robust readout system, the ESS RUs have been designed in a completely redundant way. Each redundant part of one RU is equipped with a RS485 interface and based on a Microchip PIC micro-controller and a so-called RBFE-MUX block of electronics. This block of electronics inside the ESS RU provides intelligent sensor information multiplexing, as well as the digital implementation of a resistance bridge (RBFE) for removal of different readout signal dependencies on voltage offsets, thermocouple effects, power supply and ambient temperature drifts etc. Information from the temperature sensors from four input ports of one RU is mixed between its two redundant parts in a way which minimizes the possibility of losing temperature information inside the ECAL due to malfunction of an ESS RU component.

The part of the system where sensor information is processed and interlocks are accepted/generated is based on the industrial Siemens Programmable Logic Controllers (PLCs). The ESS PLC system has been designed and built as a redundant and distributed set of modules from S7-400 and S7-300 families. Since one of the main objectives of the ESS is a very high degree of reliability, a specific ESS multi-point communication protocol that provides reliable information exchange between ESS RUs and ESS PLC also had to be designed.

Both ESS sensors and electronics of ESS RUs were tested for radiation tolerance to appropriate doses and showed no shift in any parameter, while the cross section for single-event effects has proved to be negligible [13].

The ESS performance has been tested during the ECAL integration and test-beam periods in 2006 and 2007, as well as during the ECAL SM insertion in the first half of this year. The system has shown excellent reliability. At the same time, its temperature readout system has shown to have a relative precision better than 0.02 ºC.

ECAL DCS SOFTWARE

In accordance with an official recommendation of the appropriate CERN LHC groups, all ECAL DCS applications have been developed using the commercial ETM SCADA (Supervisory Control And Data Acquisition) software PVSS 3.6 [16] and standard Joint Control Project (JCOP) framework components [17].

The heart of each control system at the LHC is a Finite State Machine (FSM) toolkit written in SMI++, a derivative of the former DELPHI controls software. The FSM enables a high level of abstraction and simplified representation of detector control systems by introducing a finite set of well-defined states, in which each of its subsystems can be, and rules that govern transitions between these states. The FSM states of each subsystem depend on the current status of the underlying hardware. At the same time, the FSM enables logical grouping of DCS subsystems into a hierarchical tree-like structure, where "parent" states are uniquely determined by states of its children and system-specific logic. Each parent in such a FSM tree can issue an action command to its children. Action commands at the lowest level imply appropriate commands to the controlled hardware.

The CMS ECAL controls software has also been implemented in this way. The software granularity is driven by the ECAL subsystem structure. The HV, LV, Cooling, PTM/HM and ESS systems are controlled by independent applications. On top of these applications, there is the ECAL Supervisory application that implements FSM hierarchical structuring of the whole ECAL controls software.

In addition, the ECAL DCS applications include numerous other functionalities, such as full parameterization and visualization of each subsystem, loading from and storing to the CMS Configuration (ORACLE) database the start-up and operational parameters for all DCS subsystems etc.

STATUS AND PLANS

The ECAL DCS has been providing support to several ECAL test setups in the last few years. All these setups have served the ECAL DCS as perfect benchmarking setups for the performance of both hardware and software prototypes of its subsystems.

At this moment, the hardware commissioning of the whole ECAL DCS is close to its final phase. The complete hardware of the ESS is installed at Point 5 and most of the interlocks have already been interconnected and tested. The PTM/HM hardware is under test in the lab and will be moved to its final location soon.

After the commissioning of the ECAL DCS hardware has been completed, the ECAL DCS software applications will be tested and tuned with the final ECAL subsystems at Point 5. After finishing both hardware and software commissioning, the ECAL DCS will enter its "routine" operational phase – for the next decade.

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