The commissioning and the first operational experiences of the CMS RPC detector control system at LHC

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1. Introduction

The Resistive Plate Chambers (RPC) detector has been chosen and integrated in the CMS Muon System [1] because of its spatial resolution (~cm) and fast time resolution (few ns), crucial requirement in the bunch crossing (BX) identification of the muon candidates generated during the proton–proton collision. The CMS RPC system is composed in its first phase by 912 double-gap chambers, located in both barrel and endcap and covering the pseudo-rapidity region of |η| < 2.1. Each RPC gap is made by two parallel bakelite plates (1−2 × 10¹⁰ Ω cm) placed at a distance of 2 mm and filled with a gas mixture of 96.2% C₂H₂F₄, 3.5% i-C₄H₁₀ and 0.3% SF₆. High voltage is applied to the outer graphite-coated surface of the bakelite plates to create the electric field inside the gas gap and to generate the charge avalanche, that induces a signal on the copper strips placed outside the gap and isolated from the graphite.

In order to achieve the operational stability and reliability of such large and complex detector, a continuous control and monitoring of the detector and its auxiliary components is required. For these purposes a specific system, the RPC Detector Control System (RCS) [2], has been implemented, aiming to control and configure the detector and its electronics, calibrate it, monitor all detector conditions (but not event data) and its performance by mean of several reference parameters that determine the effective behaviour of the detector. Therefore the RCS system has to assure the safe and correct operation 24 h/7 d of the sub-detectors during all CMS life time (more than 10 year), detect abnormal and harmful situations and take protective and automatic actions to minimize consequential damages.

2. The RCS low-level layers: description and performances

The RCS hardware is divided into several sub-systems involved in the detector operation (Fig. 1): power supply (HV and LV), environmental (humidity, temperature, and pressure), front-end electronics, gas, and infrastructures systems. From the software point of view, in accordance with the CMS official guidelines [3], all RCS applications are developed using the commercial ETM SCADA (Supervisory Control And Data Acquisition) software, PVSS 3.6 and the standard Joint Control Project (JCOP) framework components [4]. Due to the large amount of devices from different sub-systems (HV, LV, environment, gas, and cooling), the control and monitoring has to be done in parallel and distributed over different machines.

2.1. The RPC power supply system

The high granularity of the CMS RPC system and the high radiation and magnetic field environment inside the CMS experimental hall, place special demands on the power supply system. Each of the 912 chambers requires in fact two independent HV channels and two LV channels for powering up the very front end electronics (FEB), placed inside the chamber. In addition, several low voltage channels are required to supply each Link Boards Box (LBB) [6]. In order to reduce the high voltage drop along the cables, the biggest part of the power supply system is located inside the racks surrounding the detector. In this area the magnetic field can reach up to 6 × 10⁻² T, while the neutron flux for neutrons with energy more than 20 MeV is expected to be less than 100 cm² s⁻¹, giving a neutron fluence less than 5 × 10¹⁰ neutron/cm² s⁻¹. The solution chosen by the RPC collaboration for the power system is based on the CAEN EASY (Embedded Assembly SYstem) project. It consists of a master-slave architecture, that allows to separate the control part,
made by components not-radiation hard, from the supply modules and crates, that can operate in such environment.

The control operations on the power system are performed through different levels in a redundant way. On the hardware level, prompt safety mechanisms are implemented directly at the boards level, to assure fast and safe actions, by means of programmable parameters available for each channels. Additional controls are performed at the software level by the back-end applications that communicate with the hardware managed by the CAEN Mainframe SY1527 through the OPC protocol [2]. The acquisition is based on an event-driven approach where the most significant parameters are handled with a 2 s refresh time. The software part is aimed to enhance the hardware level protection by means of slower safety checks on each channel, and to provide an easy and robust interface to operate the system. Programmable actions are foreseen to switch off the LV and HV boards or perform a controlled ramp down to safer status conditions in case of high working temperature or failure of the auxiliary systems.

The power system behaviour is a crucial requirement to understand the detector response. During the last years specific test campaigns on each single component have been carried out to optimize all the power distribution line elements (e.g. power supplies, cable, connectors), in order to stabilize the dark current response from the chambers and to minimize the external sources effects. From the power supply point of view, a stable version of the HV board has been obtained, able to fulfill the RPC requirements in terms of accuracy, offset stability and reliability in different operative conditions (Fig. 2). On the LV system, the stability of supplied voltage has been reached with an acceptable ripple level of about 50–100 mV, ensuring the safe operation of the front-end chips and minimizing the external noise. The entire system in the final configuration has been working without any interruption since summer 2007, with a failure rate lower that 5% and all the repairing interventions performed without causing any delay in the detector operation.

2.2. RPC environmental and front-end electronics monitoring

The performances of the RPC detector are strongly related to the operative temperature and humidity since some detector physics parameters, e.g. the noise rate and the dark current of the chamber, strictly depend on them. To assure the quality and stability of the data taking over all the CMS lifetime, an homogeneous, high granular, and robust network of sensors has been put in place. The RPC environmental monitoring system is aimed to monitor the gas temperature and humidity, the temperature of the air inside the detector volume and of the cooling pipes (sensors located at inlet and outlet pipes), the temperature of front-end boards, and the environmental relative humidity. It is composed in total by 438 AD592BN temperature sensors and 68 HIH4000 relative humidity sensors. Both types of sensors are radiation-hard and magnetic field tolerant and powered and read back by the CAEN ADC (A3801A) boards, placed in the balcony around the detector. Additional sensors have been installed also on the front-end boards (FEB) [5] inside the chambers to monitor the working temperatures and assure the effectiveness and safety of the working condition. All the values are constantly monitored and protective actions are taken on the chamber hardware in case of high temperature (higher than 24°) or humidity (more than 70%) out of the safety ranges. During the commissioning phase tests on the thermal environmental map have been performed in order to find out the
environmental conditions with all the subsystems on and in
correlation with the cooling system efficiency, reaching a very
stable and satisfactory working condition and keeping all the
chambers below the safety detector working threshold.

2.3. Gas and external systems monitoring

In order to provide a detailed picture of the detector status, all
the information from the other sub-systems involved in the
working operation are integrated in the RCS application. A crucial
issue in the RPC system operation is represented by the gas
system condition. The entire gas distribution network is not part
of the RCS, but is controlled by a CERN centralized system, the
LHC GCS project [7], aimed to acquire the data from the
Programmable Logic Controllers (PLCs) and supervise them with
a dedicated control system. Nevertheless, all the most important
parameters monitored from the gas system (e.g. the gas quality
and the mixture composition, the chambers input and output
flows, the actual status of all the equipments involved in the
preparation and distribution of the gas mixture) are available in
the RCS in order to correlate them online with other operational
parameters and optimize the detector behaviour. In the same way
all the information concerning the CMS infrastructures (Cooling
and ventilation, Electricity distribution, Detector Safety System
(DSS), LHC, and Magnet status) are available in the RCS and used
to promptly take action in case of failure or harmful conditions.

3. The RCS software layers

All the control subsystems described in the previous sections
are able to work as stand-alone components and participate to the
RPC system operation, each covering a particular task [8].
Nevertheless, in order to gather all the information and present
them in a simplified but coherent and homogeneous view, a
supervisor layer has been implemented in the RCS. Its main aims
are to control and monitor all the sub-systems involved in the RPC
operation and present their status to the central DCS and to the
CMS Run Control during the data taking. In addition the RCS
supervisor allows one to synchronize the operation either with
the RPC DAQ, for operating the RPC in standalone mode during
the commissioning and calibration phase, and with the LHC
conditions, handling the handshake procedures and driving the
detector in safe conditions. The RCS Supervisor uses most of
the functionalities provided by the JCOP+PVSS software, such as
the finite state machine, the graphical user interface, the alarm
handler and the ORACLE database interface, that allows the
storage of the data in the CMS online database and the loading of
the hardware configuration from the CMS configuration database.

3.1. RCS supervisor architecture

The huge amount of components under the RCS control and
the high granularity of the system require to describe it in a
hierarchical way. The RCS software architecture has been
developed following a hierarchical double-tree structure: a
geographical and a hardware oriented tree (Fig. 3). This subdivi-
sion closely follows the geometry of the detector, i.e. wheels and
sectors for the barrel, discs and rings for the endcap, allowing a
close correlation with readout data. PVSS and JCOP framework
allow an easy implementation of such a structure, describing each
node through the Finite state machine (FSM) logic as predefined
objects, in charge of driving the hardware equipments and
subsystems under them. In fact they can configure, monitor, and
control all child nodes and recover from error state, assuring
partitionability, scalability and allowing a robust and powerful
management of the system. The commands, coming from the
central DCS, are propagated through the RPC FSM tree, down to
the devices where they are interpreted accordingly as hardware
commands (Fig. 3). The states and the commands for the top
nodes as well as the conjunction nodes have been chosen by CMS
in order to have a uniform structure. The states are: ON, OFF,
STANDBY, and ERROR and the commands are: ON, OFF, and
STANDBY. The use of these particular states and commands
ensures uniformity and compatibility with the central DCS,
permitting adequate transitions between the states. Their small
number and general definition makes them suitable for all sub-
detectors. The states from central DCS are translated in mean-
ingful states for RPC. For this reason a transitional state
(RAMPING) has been added to the previous states. It describes
the situation in which the high voltage of one or more chambers is
ramping up or down. The STANDBY state is used for the RPC
detector as a safe state in which the LV channels are ON, while the

Fig. 3. Structure of the hierarchy tree of the RCS. Different branches describe the RPC system from geographical and hardware points of view. All commands go down the
hierarchy, while information and error messages are reported upwards.
4. Commissioning with cosmic rays and pp collisions

Several milestones were reached in the last three years to make CMS a unique, highly efficient, and reliable detector. Since summer 2006 different global data taking campaigns were performed, operating simultaneously parts or all CMS subdetectors, the trigger, and DAQ chains as a unique system. Since then, the RPC detector has participated to the CMS global runs with an increased percentage of integrated system, reaching its final configuration during the summer 2008. They allowed to achieve the commissioning goals and to validate the detector response and performance in its final configuration, matching all the CMS requirements. The RCS was extensively tested during the hardware installation phase and already used during the commissioning phase as official tool for operating the CMS RPC detectors. After a short initial debugging phase, the system ran without problems for the entire test period, showing that the architecture of the system met the CMS requirements in speed, reliability and scalability. The RCS was proved to be a reliable tool for the safe and correct operation of the detector. Trained shifters were able to operate the detector in an easy and safe way. It was also proved the RCS capability to manage all the unexpected interrupts occurred, always keeping the detector in safe conditions. The developed RCS adequately followed the detector’s behaviour without ever loosing control of the hardware.

5. Conclusions

The RCS gives a complete solution for all auxiliary systems involved in the detector operations. HV, LV, Gas and Infrastructures systems have been operating since summer 2007 in their final configuration, as well as the final DAQ software and DCS, implemented for the detector read-out and control. The commissioning and validation of the RPC detector control system are now finished and the RCS is currently running in the operational phase. It has been successfully tested and used during the last years where CMS has been performing numerous Global Runs. The good results obtained in these years global runs and the tests performed at CERN with the final configuration demonstrated that the RCS is well designed, being able to run in a very stable and safe way for a long period in the global framework of CMS DCS.

References