Journal of Physics: Conference Series **219** (2010) 022019 doi:10.1088/1742-6596/219/2/022019

The Detector Control Systems for the CMS Resistive Plate Chamber

G. Polese [1] [2], P. Paolucci [3], R. Gomez- Reino [2], C. Viviani [4], H. Shahzad [5], T. Khurshid [5].

[1] Lappeenranta University of Technology, Lappeenranta, Finland
[2] CERN, European Organization for Nuclear Research, Geneve, Switzerland
[3] INFN, Sezione di Napoli, Italy
[4] Dipartimento di Fisica Nucleare e Teorica and Sezione INFN, Pavia, Italy
[5] National Center for Physics, Islamized, Pakistan

E-mail: Giovanni.Polese@cern.ch

Abstract. The Resistive Plate Chamber system is composed by 912 double-gap chambers equipped with about 10^4 front-end boards. The correct and safe operation of the RPC system requires a sophisticated and complex online Detector Control System, able to monitor and control $2{\cdot}10^4$ hardware devices distributed on an area of about 5000 m^2. The RPC DCS acquires, monitors and stores about 10^5 parameters coming from the detector, the electronics, the power system, the gas, and cooling systems. The DCS system and its first results, obtained during the 2007 and 2008 CMS cosmic runs, will be described in this paper.

1. Introduction

The CMS Resistive Plate Chambers (RPC) system consists of 912 double-gap chambers at its start-up in middle of 2008. A time resolution of few nanoseconds and a good spatial resolution ($\sim$ cm), make them an optimal choice for the muon trigger [1]. A continuous control and monitoring of the detector, the trigger and all the ancillary sub-systems (high voltages, low voltages, environmental, gas, and cooling) is required to achieve the operational stability and reliability of such a large and complex detector and trigger system. The role of the RPC Detector Control System is to monitor the detector conditions and performance, control and monitor all sub-systems related to RPC and their electronics and store all the information in a dedicated database, called Condition DB. Therefore, the RPC DCS system has to assure the safe and correct operation 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.

The RPC DCS hardware is subdivided in several sub-systems (Fig. 1): High Voltage (HV), Low Voltage (LV), environmental (humidity, temperature, and pressure), front-end electronics, gas, and cooling systems. From the software point of view, in accordance with the CMS official guidelines [8], all RPC DCS applications have been developed using the commercial ETM SCADA (Supervisory Control And Data Acquisition) software, PVSS 3.6 [2] and the standard Joint Control Project (JCOP) framework components [3]. Due to the large amount of devices from different sub-systems (HV, LV, environment, gas, and cooling), the control and

© 2010 IOP Publishing Ltd

monitoring has to be done in parallel and distributed over different machines. Nevertheless all the subsystems are handled and controlled by the RPC supervisor, aimed to gather and summarize all the information in order to present a simplified but coherent and homogeneous interface to the operators.
The RPC DCS 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, for storage of the data in the CMS online database and the loading of the hardware configuration from the CMS configuration database. The present paper is mainly focused on the design, realization and performance of the power and environmental systems. The Infrastructure and Gas systems [6] are instead developed centrally by CMS and all information are monitored and shared through the Central DCS using the Data Interchange Protocol (DIP) middleware.

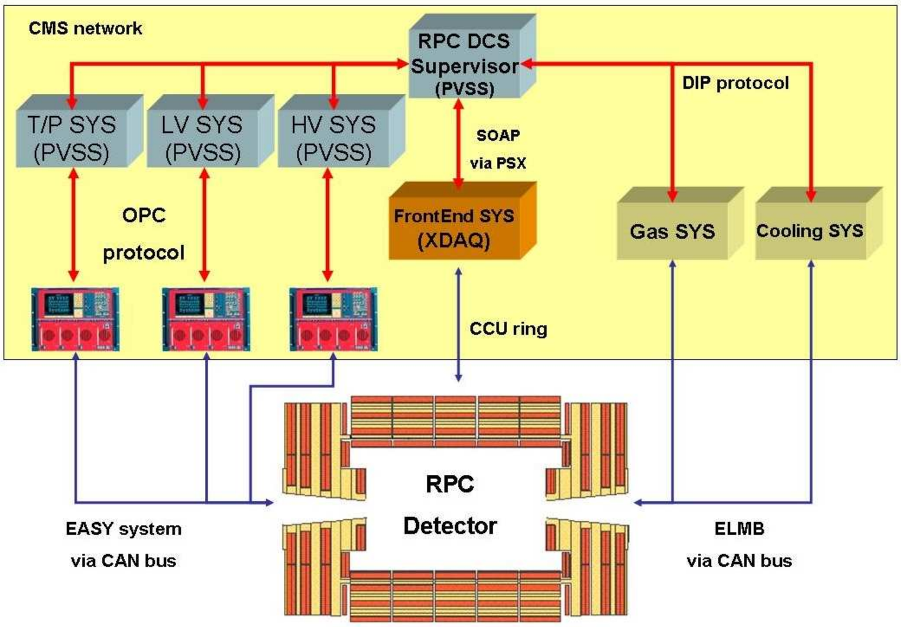

Figure 1. The CMS RPC detector control system layout.

2. The CMS RPC system description

The RPC system is divided in two regions: barrel ($0 < |\eta| < 1.2$) and endcap ($0.9 < |\eta| < 1.6$). The barrel consists of 5 wheels each with 12 sectors, equipped with 4 muon stations. The two innermost stations are made of a Drift Tube chamber (MB1 or MB2), surrounded by two RPCs (RB1-in, RB1-out and RB2-in, RB2-out). The two outer muon stations are made by a DT chamber (MB3 and MB4) coupled with two RPCs (RB3 and RB4). In some special sectors there are four RB4 (sector 4) or one RB4 (sector 9 and 11). In total there are 4 muon stations and 6 RPC layers, used for triggering and detect muons. Each endcap is made by 3 iron disks and 4 muon stations of Cathode Strip Chambers and RPCs. The muon stations contain one layer of double-gap RPC each and are divided along the r-coordinate into 3 chambers (REs/1, REs/2 and REs/3, where s = 1,...,4 is the station number). Chambers RE2/1, RE3/1 and RE4/1 cover 20° in ϕ, whereas all the other RE cover 10°.

An RPC gap is made by two parallel bakelite plates (1-2 $10^{10}\Omega$ cm) placed at a distance of 2 mm and filled with a gas mixture of 96.2% $C_2H_2F_4$, 3.5% $i-C_4H_{10}$ and 0.3% of SF_6. High voltage is applied to the outer graphite-coated surface of the bakelite plates in order to have an electric field inside the gas gap able to generate a charge avalanche along the track of an ionizing particle. The avalanche induces a signal on the copper strips placed outside the gap and isolated from the graphite. A barrel RPC chamber schema, with two double-gaps and a strip plane in the middle, is shown here (Fig. 2). There are 16 different typologies of chambers, but all of them are made by two or three double gaps assembled in a common mechanical framework, with a read-out strips plane placed in between. Chambers in the barrel are equipped with two or three rows of 6 front-end boards [5] each connected to 16 readout strips. The total number of FEBs per chamber is either 12 or 18 (three double gaps), and 10 in some special smaller RB4. Instead, endcap chambers contain three or four FEBs, each connected to 32 strips. The high voltage connection of the 2 or 3 upper and lower gaps are joint together (Fig. 2) in order to reduce the number of HV channels keeping the possibility to have different gap voltages in every chamber.

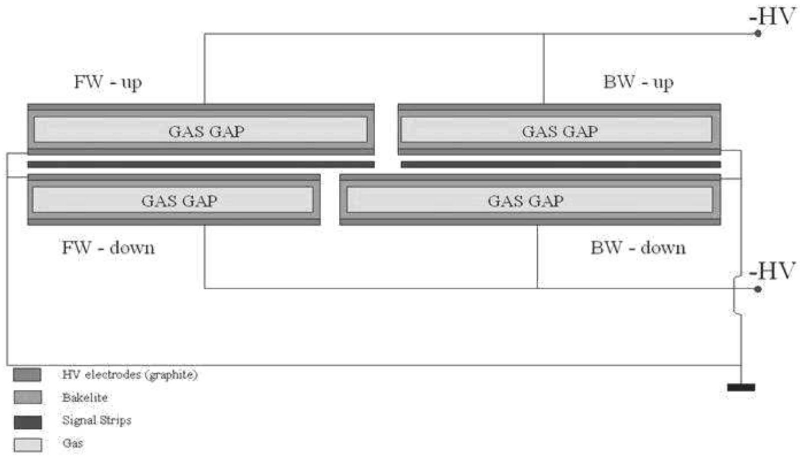

Figure 2. A barrel RPC chamber made by two double-gaps and with a strip plane in the middle.

3. The RPC Power system

3.1. The High and Low Voltage system

The complexity and high granularity of the RPC system and the hostile environment (high magnetic field and high radiation flux) in which it will operate, imposed challenging constraints on the development of the power distribution system. In the muon system, a large part of the power system is located close to the detector and in particular inside the racks placed around the barrel wheel and the endcap disk. In this area the magnetic field can reach up to $6{\cdot}10^{-2}$ Tesla, while the radiation is up to 10^7 proton/cm^2 and $5{\cdot}10^{10}$ neutron/cm^2. The power system has been designed taking into account the environmental requirements and the necessity to minimize the probability to have dead or inefficient regions due to the failure of some power supply channels. Every RPC chamber has been equipped with two independent HV channels (one per layer) and two LV channels choosing a good compromise between the cost and granularity. In addition, four low voltage channels are needed to supply each Link Boards Box (LBB) [7], aimed to collect data from each chamber, synchronize and send them to the trigger and readout chain in control room.

In conclusion, the entire RPC power system consists of:

- 912 high voltage channels,

Table 1. Requirements for the HV and LV system for RPCs.

Power Supply	High Voltage	LV for FEB	LV for LBB
Hostile Environment	Yes	Yes	Yes
Voltage	12 kV	7 V	4 V
Current	1 mA	3 A	14 A
Programmable Voltage	0–12 kV	0–9 V	0–5 V
Current Precision	0.1 μA	100 mA	100 mA
Voltage Precision	$<$ 10 V	100 mV	100 mV
Trip Settings	0–100 s	0–10 s	0–10 s

- $\simeq$ 1000 low voltage channels for front end boards on the chambers,
- $\simeq$ 300 low voltage channels for the link boards.

The solution chosen by the RPC collaboration for the power system is based on the CAEN EASY [9](Embedded Assembly SYstem) project,which consists of components made of radiation - and magnetic - field - tolerant electronics and based on a master-slave architecture. Branch controller boards, located inside the CAEN SY1527 mainframe, act as master, and are aimed to control and monitor one or more slaves. The master is placed in a safe and accessible area as the electronic room. The slave part is composed by crates with a dedicated backplane, housing a certain number of different boards: power supplies, ADC, and DAC. It can be placed close to the detector, being based on radiation tolerant electronics, and is designed to be modular and multifunctional in order to be able to have mixed systems containing both HV and LV power supplies. Nevertheless, the RPC collaboration decided to collocate the entire HV system in an accessible area (the CMS counting room) to easily fix any problem regarding the connection and the distribution of the HV. The LV system, instead, has the slave part (power supply) placed in racks surrounding the detector, and the master part in the counting room.

3.2. Performances

The Power system has been working stably, in its final configuration, during all the operational phases since summer 2007. It has been proved to be reliable, with a failure rate less then 5%, and all the reparations have been realized without delaying the operations.
From the software point of view, the entire system is described by more then 20000 parameters, acquired from the hardware at about 100 MB/hour. The communication with the CAEN power system is managed through the OPC protocol [4] and the necessary software applications are distributed over four servers for resource optimization and load balancing. The acquisition is based on an event-driven approach and the most significant parameters are handled with a 2 s refresh time and an average load-per-pc of about 5000 items. The OPC server used, developed by CAEN, is the “CAEN OPC server”, version 3.0. Preliminary studies on timing performance with an increasing number of hardware channels were performed using this OPC server/client configuration and showed a reasonable and effective behavior in the switching and setting operations (Fig. 3). Hence the time required during the switching on operation to bring the detector from OFF to ON state has been calculated to be about 470 s, mainly due to the detector mode operation (e.g. ramping up settings).

4. Environmental network

The performances of the RPC detector are strongly related to the temperature and humidity in the CMS cavern. In particular the noise rate and the dark current of the chambers depend on

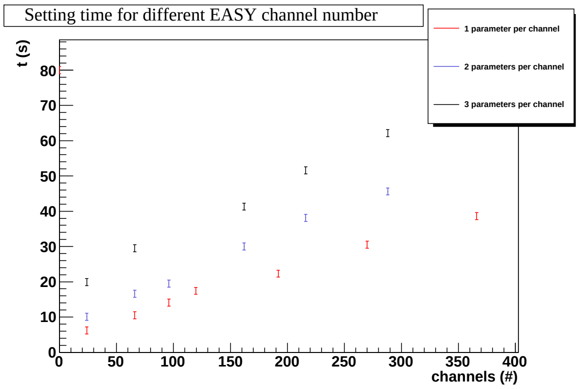

Figure 3. Time required to set different parameters for an increasing number of CAEN channels using PVSS and CAEN OPC Server 3.0. This configuration is representative of the max loads configuration used per SY1527 in our configuration.

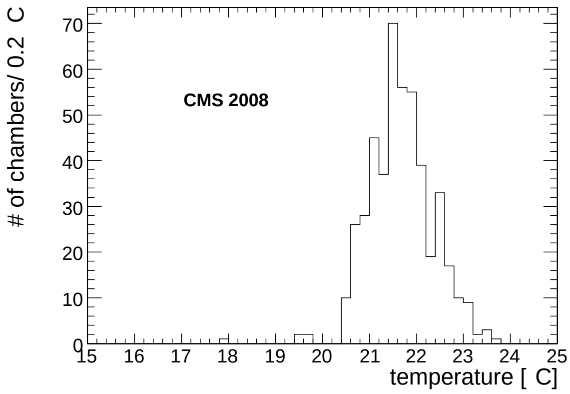

Figure 4. Barrel chambers temperature distribution during a CMS long data taking period. All the temperatures are below 25 °C, RPC safety working condition threshold.

these two parameters. For this reason monitoring the gas temperature, the humidity and the temperature outside of the chambers is crucial. The environmental sensor network is composed by about 550 sensors to measure the temperature of the iron gaps, where the chamber are placed, 40 sensors to measure the temperature of the gas and 40 relative-humidity sensors. Several humidity sensors have been installed on crucial positions on the endcap to improve the environmental condition mapping. The temperature sensor is the AD592BN, made by Analog devices, whereas the sensor HIH4000 is used to measure the relative humidity. They assure the robustness, reliability and precision required and can operate in the radiation and magnetic field environment as described in Table 2. Both sensors are powered and read by the CAEN ADC (A3801A) boards, equipped with 128 channels and a 12 V input stage. All ADC boards are placed in the balcony around the detector, in the same EASY3000 crates used for LV.

Table 2. Requirements for the environmental network for RPCs.

Environmental sensor	Temperature	Humidity
Hostile Environment	Yes	Yes
Input range	-10$°C$ +60 $°C$	0–100 % RH
Accuracy	0.1 $°C$	±2.5% RH

Additional sensors have been installed also on the electronics boards inside the chambers to monitor the working temperate and assure the effectiveness and safety of the working condition. The RPC is equipped with about 7000 front-end boards (FEB) [5], aimed to discriminate and form the signals coming from the read-out strips and transmit them to the Link Boards [7]. Every FEB has one or two temperature sensors (AD7417) with a nominal accuracy of 0.25°C/LSB. Control and communication are developed via a CCU ring through XDAQ, the online CMS framework, and then these data are sent via SOAP messages to PSX/PVSS [10], with an average bandwidth of 2KB/s measured during normal operation.
All the environmental information is gathered and controlled by a dedicated PVSS application, able to correlate them and take protective actions in case of harmful situations. During the commissioning and operational phase during the past two years, this system has been

Journal of Physics: Conference Series **219** (2010) 022019 doi:10.1088/1742-6596/219/2/022019

working stably and reliably, and has been able to spot any problematic effects correlated with environmental condition changes. An example of the chambers temperature distribution during one long data-taking period with all the sub-systems fully operative is shown in Fig. 4.

5. External systems information

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 RPC DCS 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 RPC DCS, but is controlled by a CERN centralized system, the LHC GCS project [6], 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 RPC DCS in order to correlate them online with other operational parameters and optimize the detector behavior. 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 RPC DCS and used to promptly take action in case of failure or harmful conditions.

6. The RPC DCS Supervisor

6.1. Architecture

The RPC DCS software architecture has been developed following a hierarchical double-tree structure: a geographical and a hardware oriented tree (Fig. 5). Both trees give useful information on the system from different points of view. The hardware tree shows the status of all the equipment involved in the operation and allows one to find out and handle problems occurring in a particular hardware component, involving several detector parts. The geographical tree, instead, describes the system from the detector point of view, focusing on the location of each component on the detector. This subdivision 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 the JCOP framework allow for an easy implementation of such a structure. Every tree node is described by predefined objects, Control Unit (CU) and Logical Units (LU) that, with different task and privileges, are aimed to drive the behavior of the hardware equipments and subsystems under them. In fact, they can configure, monitor and control all child nodes, and recover from an error state. This facility assures partitionability and scalability, allowing for a robust and powerful management of the system. At the lowest level, as leaves of the tree, there are different logical groups describing the hardware devices: HV, front-end LV, trigger LV power supply, and environmental systems. These tree nodes, representing electronic channels, are described instead by Device Units (DUs). Each DU is the interface to a hardware component; it translates the received commands, understands the device states and generates eventual alarms. The HV and LV channels, the power supplies, and the slave crates are managed separately through dedicated DUs. The root (top) node of the RPC DCS is connected directly to the CMS central DCS system and is used to communicate and exchange actions, states and commands. The commands, coming from the central DCS, are propagated through the RPC FSM tree down to the devices. Here they are interpreted accordingly as hardware commands. The hierarchical tree structure allows only vertical data flow: commands move downwards, while alarms and state changes propagate upwards (Fig. 5).

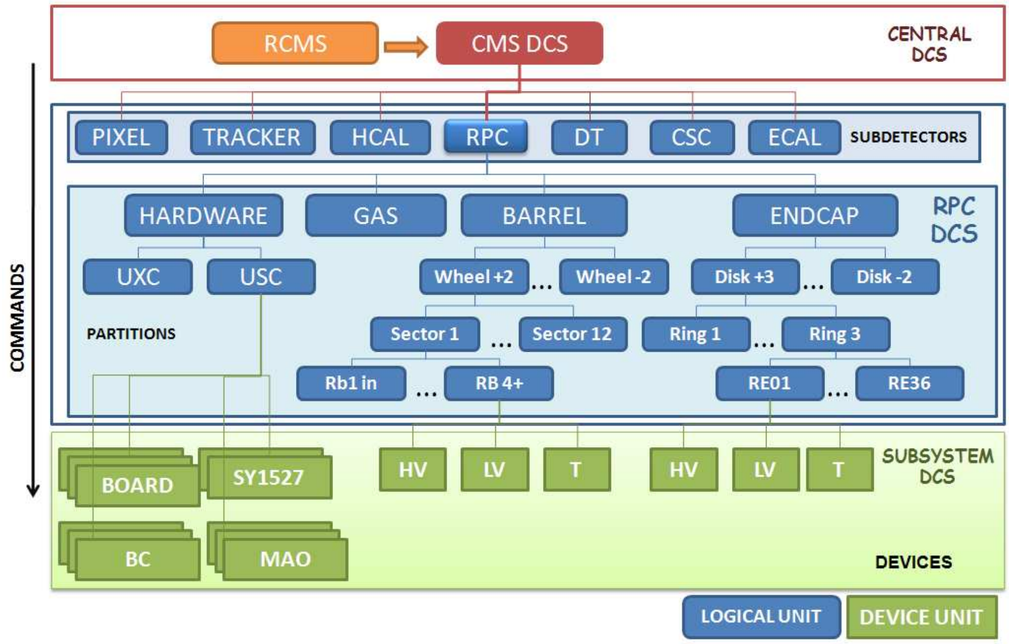

Figure 5. Structure of the hierarchy tree of the RPC DCS. Different branches describe the RPC system from the geographical and hardware points of view. All commands go down the hierarchy, while information and error messages are reported upwards.

6.2. The Finite State Machine

In order to fulfil a high rate of automation in control processes, reduce human errors, unavoidable in repetitive action, and optimize recovery procedures in case of undesired states, all the RPC DCS hierarchy nodes are implemented through a Final State Machine (FSM) mechanism. It offers an easy, powerful and safe way to get the full detector control, through the definition of a finite number of states, transitions, and actions. It allows one to summarize the detector status through a limited number of states, drive it to predefined configurations and translate all the operation modes in simple actions, hiding to the operator the complexity of the actions required. The FMS toolkit in PVSS is based on SMI++ [12] and provided by the JCOP framework. 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. The commands are: ON, OFF, and STANDBY. The use of these particular states and commands ensures uniformity and compatibility with the central CMS 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 meaningful 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 high voltages are at an intermediate and safe value. This state has been implemented for test and calibration runs, for period with a "not stable" beam, or magnet ramping conditions.

6.3. The Graphical User Interface (GUI)

The GUI is developed to be an intuitive tool to control and monitor the detector, easy to use also for non-experts and able to protect the system from any dangerous action. It is a collection of panels written in PVSS language and offers the following functionalities:

- easy navigation throughout the entire system structure, thanks to a combination of text, graphical objects and synoptic diagrams;
- visualization and setting of any process variable;
- global parameter setting, thus speeding operations and reducing human errors;
- plots, diagrams, histograms, and tables for a first online analysis of the detector behavior;
- complete visualization of the alarm condition on all critical elements.

To fulfill the above functionalities, approximately 40 panels (in a tree structure) have been designed, following the naming conventions and the color codes decided centrally by the CMS DCS group. Examples of RPC DCS panels are shown in Fig. 6. The GUI allows for a complete control of the entire RPC system and therefore, to prevent any human error, a different access levels have been set. The following self-explanatory groups: PVSS expert, RPC expert, and RPC user have been successfully tested during our pilot runs.
An indispensable feature of any control system is the alarm handling. An alarm is issued every time the system unwontedly leaves the desired state, or if a given parameter deviates from a predetermined range. Sets of alarm conditions severity levels and recovery procedures have been defined and implemented for all the critical hardware parameters in order to have a very fast alert of any abnormal condition. The presence of an alarm is promptly signaled, completed with information on its origin and severity level, by the PVSS alarm handling system.

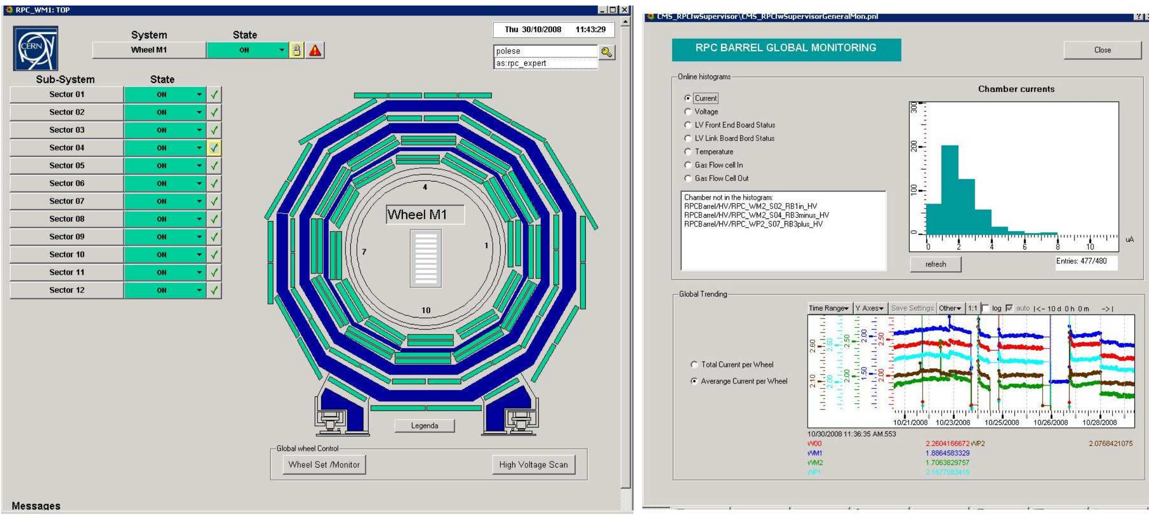

Figure 6. Layout of the Barrel Wheel panel (a). It offers an overview of the children nodes status (on the left), a visual summary of the status of all selected wheel chambers and the possibility to set and monitor all working parameters, depending on the user privileges. Figure (b) shows one of the tools for online detector behavior analysis.

6.4. Integration in central DCS and Run Control

The RPC DCS is directly connected with the central DCS. Thus the central DCS can propagate commands, alarms, and messages directly to the RPC DCS, and publish the RPC status condition to the CMS Run Control during the data taking by means of the FSM (Fig. 7). In this way, a bidirectional communication between the RPC DCS and run control is provided, in order to synchronize the status of the detector with the physics data taking operation. The RPC DCS is also able to operate in standalone mode, in order to be used during the commissioning and calibration phase, by means of a direct connection to the RPC Run control. This allows one to synchronize the configuration operations among different RPC parts, check the status of the entire RPC system and centrally manage warning and error messages coming from different RPC partitions.

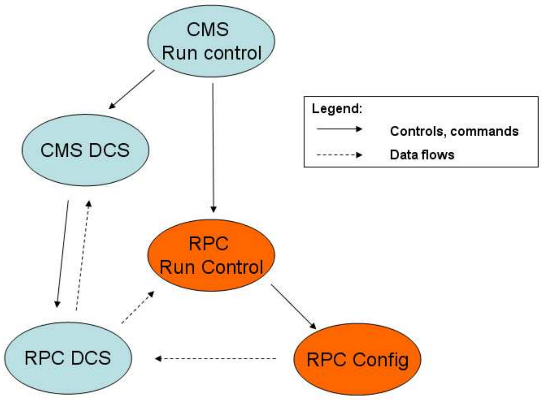

Figure 7. Logical layout RPC DCS with other DAQ subsystems.

6.5. Database

The hardware description and the configuration of the RPC system are particularly laborious, due to the large number and heterogeneity of its elements, and require database infrastructures to keep track of the different running configurations. All the structural information, geographical position and configuration parameters (such as calibration constants, voltage settings, and alarm thresholds), necessary to put the detector in running condition, are stored in a central relational database, called Configuration database, that is based on the ORACLE technology.

On the other hand, all the information regarding the running conditions and non event data controlled by the RPC DCS need to be stored in order to monitor the system behavior over time. For this purpose a Condition database, based as well on ORACLE technology , is used to archive all parameters relevant to both electronics and detectors performances. These pieces of information allow foe the optimization of the working condition and studies of the equipment response during different phases of the experiment and are useful to understand the ageing behavior of the detector. In the final configuration the amount of RPC DCS data stored would be about 10 GBytes per year, almost 0.5% of the monitored information. The biggest part of these data is represented by measurements of chamber dark currents. The interface between PVSS and the different databases is developed using a dedicated PVSS manager for ORACLE DBs, able to assure reliability, redundancy, and stability of the storage system.

7. The RPC DCS performance during the CMS global runs

The RPC DCS has been extensively tested during the CMS "Global runs", periods of data taking with cosmics and the whole RPC system has been commissioned using this data. The RPC chambers were operated with the final configuration of the power systems, and the CMS DAQ software, data quality monitor (DQM), and DCS were implemented for the detector readout and control. The DCS proved to be a reliable tool for the safe and correct operation of the detectors, and trained shifters were able to operate the detector in a easy and safe way. It has been

also successfully integrated into the Central DCS and was able to publish its state and receive commands from it. After a short debug phase, the system ran without major inconveniences for the entire period and it has proved to be able to properly manage interruptions.
Regarding databases, the entire configuration was stored in the CMS Configuration database. Connection and communication were proven to be stable, reliable and satisfactory. About 2 GBytes of Condition data was collected and stored in the CMS condition database at a storing rate of 30 MBytes/day with a prescale factor of about 400 with respect to the data acquired. All these pieces of information are then transferred to the offline database and used in the offline analysis of the detector and trigger performances.

8. Conclusions

The RPC DCS gives a complete solution for all auxiliary systems involved in the detector operations. HV, LV, and Gas 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.
From the hardware point of view, the entire power system has been delivered, installed and tested intensively at CERN during the last two years, as well as the entire environmental sensor network. The commissioning and validation of the RPC detector control system are now finished and the RPC DCS is currently running in the operational phase. From the software point of view, the RPC DCS system, developed following the guidelines of the DCS central group, was proved to be reliable and stable, able to drive the detector behavior during all operative phases. It is demonstrated to be a useful tool for a prompt detector analysis and a powerful tool to prevent serious damages. It has been successfully tested and used during the last 2 years where CMS has been performing numerous Global Runs. The good results obtained in these 2 years global runs and the tests performed at CERN with the final configuration demonstrated that the RPC DCS is well designed and is able to run in a very stable and safe way for a long period.

References

[1] CMS Collaboration, "Muon Project", CERN/LHCC 94-38, 15 December 1997.
[2] "ETM professional control: PVSS (Prozess Visualisierungs und Steuerungs System) SCADA tool", http://itcobe.web.cern.ch/itcobe/Services/Pvss/welcome.html .
[3] M. Beharrell et al. , " Technology Integration in the LHC experiments Joint COntrols Project, CHEP01, Beijing, September 2001. http://cern.ch/itco/Projects-Services/JCOP/.
[4] OPC Foundation, http://www.opcfoundation.org.
[5] M. Abbrescia et al. , "New developments on front end electronics for the CMS Resistive Plate Chambers," Nucl. Instrum. Meth. A 456 (2000) 143.
[6] R. Barillere et al., "LHC GCS: A Homogeneous Approach for the Control of the LHC Experiments' Gas Systems", Proceedings of ICALEPCS 2003, Gyeongju, Korea, 2003.
[7] K. Bunkowski et al., "Pattern Comparator trigger algorithm implementation in FPGA", Proc. SPIE 5125, 165-174
[8] R. Arcidiacono et al. , "CMS DCS design concepts", prepared for 10th International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS 2005), Geneva, Switzerland, 10–15 Oct. 2005.
[9] CAEN S.p.A. Costruzioni Apparecchiature Elettroniche Nucleari, http://www.caen.it/nuclear/easy info.html .
[10] J. Gutleber and L. Orsini," Software Architecture for Processing Clusters based on I2O", Cluster Computing, the Journal of Networks, Software and Applications, Kluwer Academic Publishers, 5(1):55-65, 2002.
[11] M. Abbrescia *et al.*, "The gas monitoring system for the resistive plate chamber detector of the CMS experiment at LHC," Nucl. Phys. Proc. Suppl. **177-178** (2008) 293.
[12] B. Franek and C. Gaspar , "SMI++: Object oriented framework for designing and implementing distributed control systems", presented at 2004 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS / MIC), Rome, Italy, 16–22 Oct. 2004.