THE ATLAS DETECTOR CONTROL SYSTEM

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Abstract

The ATLAS experiment is one of the multi-purpose experiments at the Large Hadron Collider (LHC), constructed to study elementary particle interactions in collisions of high-energy proton beams. Twelve different sub-detectors as well as the common experimental infrastructure are supervised by the Detector Control System (DCS). The DCS enables equipment supervision of all ATLAS sub-detectors by using a system of >130 server machines running the industrial SCADA product PVSS. This highly distributed system reads, processes and archives of the order of 10^6 operational parameters. Higher level control system layers allow for automatic control procedures, efficient error recognition and handling, and manage the communication with external systems such as the LHC. This contribution firstly describes the status of the ATLAS DCS and the experience gained during the LHC commissioning and the first physics data taking operation period. Secondly, the future evolution and maintenance constraints for the coming years and the LHC high luminosity upgrades are outlined.

INTRODUCTION

The ATLAS experiment [1] at the LHC aims to study the physics of high energy particle interactions in a previously unexplored energy domain. The detector elements are distributed over a cylindrical volume of 25 m diameter and 50 m length. More than 4000 people of 176 institutions in 40 countries contribute to the project.

The DCS has the task to permit coherent and safe operation of ATLAS and to serve as a homogeneous interface to all sub-detectors and the technical infrastructure of the experiment. The DCS must bring the detector into any desired operational state, continuously monitor and archive the operational parameters, signal any abnormal behavior. A more detailed description of the complete ATLAS DCS and specific sub-detector control system hardware and software can be found in [1, 2] and references therein.

OVERALL SYSTEM DESIGN

The DCS was designed and implemented within the frame of the Joint Controls Project (JCOP) [3], a collaboration of the CERN controls group and DCS teams of the LHC experiments. Standards for DCS hardware and software were established together with implementation guidelines both, commonly for JCOP and specifically for ATLAS.

The Front-End (FE) equipment consists of purpose-built electronics and their associated services such as power supplies or cooling circuits. For the implementation of the

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DCS Back-End (BE), the industrial Supervisory Controls And Data Acquisition (SCADA) product *PVSS* serves as base software. On top of PVSS, the JCOP Framework facilitates the integration of standard hardware devices and the implementation of homogeneous controls applications. The BE is organized in three layers (see Fig. 1): process control of subsystems, a single control station for a sub-detector allowing stand-alone operation, and global stations with service applications and operator interfaces.

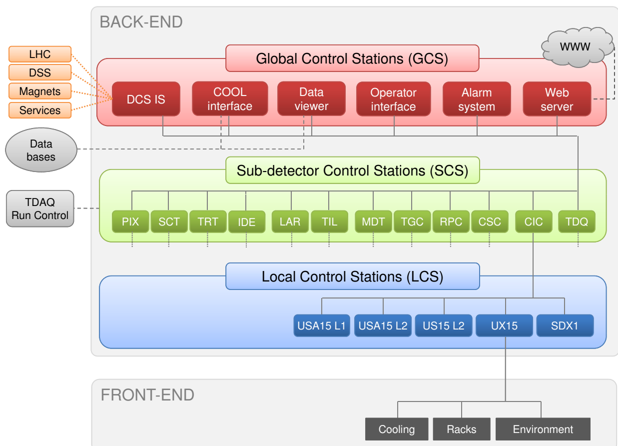

Figure 1: ATLAS DCS architecture.

SYSTEM STANDARD BUILDING BLOCKS

Front-End

The DCS FE equipment had to meet common requirements such as low cost, low power consumption, and high I/O channel density. For equipment interconnection, the CAN industrial field-bus and the CANopen protocol is used wherever possible and appropriate. Electronics in the detector cavern had to allow for remote firmware upgrades, be insensitive to magnetic fields, and be tolerant to radiation exposure expected during the experiment lifetime.

ELMB: A low-cost custom-built I/O concentrator, the Embedded Local Monitoring Board (ELMB) [4] was developed as common solution for interfacing custom designs to the DCS. The ELMB board ($50 \times 67\,\mathrm{mm}^2$) features a 8-bit 4 MHz micro-controller with 64 analog and 32 digital channels and a CAN bus interface. The board is tolerant to strong magnetic fields and radiation hard for integrated doses up to 50 Gy. Further, the ELMB can be embedded within custom designs and has a modular, remotely extendable firmware with a general purpose CANopen I/O application. More than 10000 ELMBs are in use within all LHC experiments, over 5000 alone within ATLAS.

Standardized Commercial Equipment: The industrial standard VME is used to house electronics. For all crates, monitoring is implemented for temperature and general status information as well as power and reset control. The detector components are powered by different types of industrial power supplies featuring control of voltages/currents, over-voltage/current protection, and thermal supervision.

Back-End

DCS Control Station PC: The hardware platform for the BE system are industrial, rack-mounted server machines. Two different standard machine types, one for applications requiring good I/O capability, a second for processing-intensive applications with I/O via Ethernet connectivity. Both models feature redundant, hot-swappable power supplies and disk shadowing.

PVSS: The SCADA package *PVSS* (re-branded to *SIMATIC WinCC OA*) is the main framework for the BE applications. Four main concepts of PVSS make it suitable for a large scale control system implementation:

- Generic types of control process templates may be used depending upon the type of the required application avoiding unnecessary overhead.
- Each PVSS application uses a local database for the storage of control parameters providing synchronized access for all connected processes. Data processing is performed with an event-based approach and data is made persistent by archiving selected DCS parameters to an external Oracle database.
- Different control systems can be connected via LAN to form a *Distributed System* allowing for highly scalable remote data access and event notification.
- A generic Application Programming Interface (API) allows to further extend the functionality of control applications.

Front-end interface software: For interfacing the front-end devices with PVSS, the industry standard OPC was chosen. Commercial equipment manufacturers as well as developers of custom devices provide the *OPC servers* for which PVSS provides an OPC client. For the ELMB CAN bus readout and control, a dedicated CANopen OPC server has been developed. Device types for which OPC could not be used due to maintenance or platform constraints (OPC is limited to MS Windows$^{\mathrm{TM}}$), custom read-out applications were interfaced to PVSS using the CERN standard middle-ware *DIM* [5]. PLCs are interfaced to PVSS via Mod-Bus.

The Finite State Machine Toolkit: The JCOP FSM [6] provides a generic, platform-independent, and object-oriented implementation of a state machine toolkit for a highly distributed environment, interfaced to a PVSS control application. The attributes of an FSM object instance are made persistent within the associated PVSS application database. This allows for archiving of the FSM states and transitions, and integration of the FSM functionality into PVSS user interfaces.

INTEGRATION AND OPERATION

Control Hierarchy, Error Handling, Operation

The complete DCS BE is mapped onto a hierarchy of Finite State Machine (FSM) elements using the FSM toolkit. State changes are propagated upwards and commands downwards in the hierarchy allowing for the operation of the complete detector by means of a single

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FSM object at the top level. A fixed state model (see Fig. 2) has been applied, reflecting detector conditions for which physics data taking is optimal (READY) or compromised (NOT_READY), or the detector has been turned off (SHUTDOWN). A special STANDBY state is reserved for detectors with intermittent stage for unstable beam conditions. The state UNKNOWN is used when the actual condition cannot be verified. TRANSITION signals a transient state, e.g. ongoing voltage ramps. The actual state of these logical objects is determined by the states of the associated lower level objects (children) via state rules. The lower level objects may follow a more sub-system-specific state model for which guidelines exist.

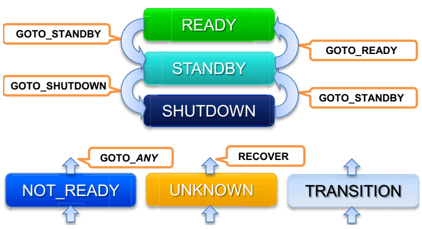

Figure 2: State model for high level objects.

For each critical parameter, alarms can be configured and are classified into one of the severity *Warning*, *Error*, or *Fatal*. To avoid the accumulation of a large number of alarms on the user interface, a masking functionality has been added to hide past occurrences e.g. after a follow-up has been initiated.

Each FSM object in the lowest hierarchy level has an attribute called *Status* which assumes the highest severity of alarms active for the respective device. The Status is then propagated up in the FSM hierarchy and thus allows for error recognition within the top layers of the detector tree and permits to identify problematic devices by following the propagation path downwards.

The DCS is operated from two primary, remotely accessible user interfaces – the FSM Screen for operation of the detector Finite State Machine hierarchy (see Fig. 3) and the Alarm Screen for alarm recognition and acknowledgment. Static status monitoring is provided by web pages on a dedicated web server allowing to quickly visualize all high level FSM user interface panels world-wide and without additional load of BE control stations.

Sub-Systems and LHC Interaction

The DCS of 9 main ATLAS sub-detectors, 3 forward detectors and common services have been integrated into a big distributed system with more than 10^7 individual parameters and subsequently condensed into approximately 10^5 state machine objects (see Table 1).

The data exchange between the ATLAS DCS and external control systems is handled via a dedicated, DIM-based data exchange protocol. All external control systems are homogeneously interfaced to the ATLAS DCS using dedicated DCS Information Servers. A generic data integrity monitoring has been implemented signaling any error condition related to the data quality and availability for the more than 20 different providers.

Table 1: Detector Sub-system Statistics. For each detector component, the # of server control stations and associated PVSS applications, the # of archived parameters, the total # of PVSS parameters, and the # of FSM objects are shown.

System	Component	#Servers (Appl.)	#Archived PVSS	#Total Parameters	#FSM Objects
Inner Detector	Pixel	11(12)	57k	1'086k	9.1k
	Silicon strips	11(11)	106k	1'265k	14.7k
	Transit. radiation	11(11)	69k	123k	13k
	Common services	7(8)	16k	494k	3.7k
Calorimeters	Liquid Argon	13(13)	27k	910k	8.3k
	Tile	5(5)	51k	719k	2.4k
Muon Spectrometer	Drift tubes	29(29)	214k	3'229k	19.2k
	Cathode strip	2(2)	1.3k	109k	0.6k
	Resistive plate	7(7)	139k	1'597k	2.5k
	Thin gap	7(7)	81k	1'225k	10k
	Common services	2(2)	0.7k	55k	0.04k
Forward detectors		4(4)	4.9k	194k	0.9k
Common Services	Counting rooms	7(7)	23k	568k	4.7k
	Trigger and DAQ	2(2)	11k	386k	1.3k
	External+safety	4(6)	8.0k	144k	0.4k
	Global services	9(13)	1.2k	222k	0.4k
Total		131(139)	809k	12.3M	91.2k

The interaction with the operational states of the LHC machine introduces a dynamic element into the operational model. During unstable beams phases (injection, ramp, etc.), the Silicon tracker and Muon detectors must remain at reduced voltage levels. This and additional beam-safety constraints require a hand-shake procedure with the LHC operators. Almost all beam-related actions – ramping the detector voltages depending on beam states with previous cross-checks on detector state and background rates – have been automated within DCS. This leaves DCS the full control over the LHC fill cycle, just requiring operator confirmation for beam injection and beam adjustments after stable beam periods. Finally, DCS is used for continuous monitoring of beam background rates and luminosity information during LHC fills. Figure 4 shows the evolution of typical LHC related parameters at the start of a fill such as beam energy and intensity, luminosity, and the change of voltage levels for two selected channels.

MAINTENANCE AND UPGRADES

Long-Term Maintenance and Organization

The DCS undergoes continuous consolidation, mostly driven by operational requirements, e.g. increasing automation for recurring problems such as power supply trip recovery or readout re-initialization after failures. As for the initial developments, common approaches are used as much as possible in order to limit the amount of potential implementation flaws and ease further maintenance. Some weak points requiring major effort during the future maintenance and consolidation include:

DCS control station upgrade: The usual life cycle of server machines of a maximum of 5 years requires hardware and operating system upgrades. A particular weakness is the choice of hardware I/O modules (e.g. CAN in-

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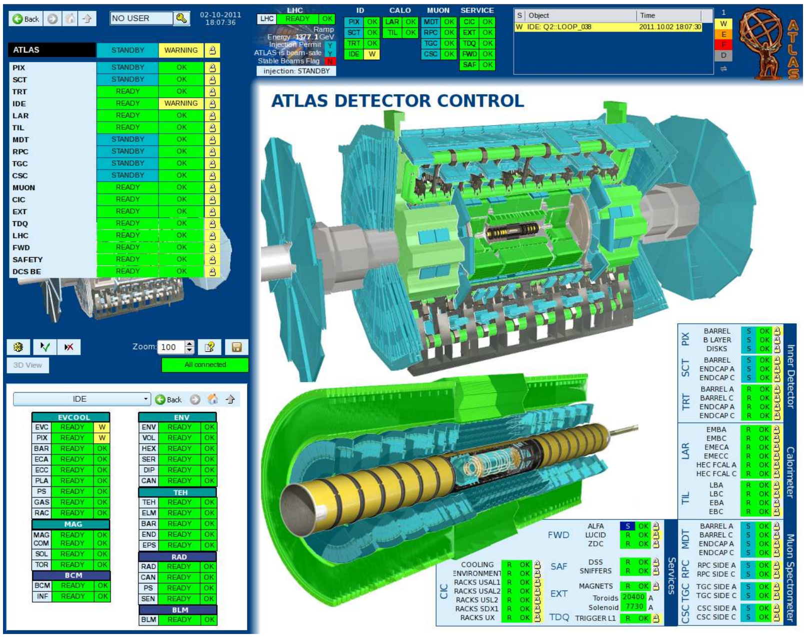

Figure 3: Operator interface (FSM Screen) showing the detector in *STANDBY* configuration during LHC ramp-up. The top hierarchy level object is shown together with its children objects (top left) and the associated main panel (bottom right). The UI allows the navigation to any FSM object and associated panel within the whole ATLAS DCS hierarchy. On the top right, a list of objects with non-OK Status allow shortcut navigation to problems.

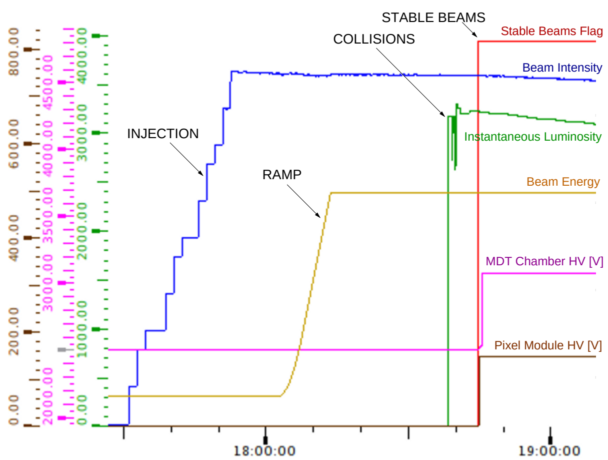

Figure 4: Initial phase of a LHC fill displayed using DCS parameters. The DCS response to the stable-beams signal received from the LHC is illustrated by two selected high voltage channels which are ramped to nominal values.

terface cards) using the PCI bus which have a short life cycle. In the future, USB and/or Ethernet interface adapters will be used which at the same time allow to increase the amount of bus connections per server machine. This enables the use of fewer cost-effective high-performance machines with a high number of cores running multiple DCS applications, or multiple virtual hosts.

Front-end interface software: The use of OPC allowed some degree of standardization of the FE interface software. However, it remains restricted to the Windows platform and lacks security mechanisms. Development activity has started to use OPC Unified Architecture (UA) – a platform independent successor of OPC with greatly increased flexibility, built-in security mechanisms, and the possibility to embed servers into electronics devices.

Future Upgrades

In the upcoming years, the LHC will undergo luminosity upgrades in several stages. Within the next 20 years, the maximum instantaneous luminosity will increase by a factor of 10 and the accumulated dose by a factor of 100 compared to the initial LHC design. This introduces more stringent requirements for DCS on-detector components such as the ELMB. A successor board has been proposed – the ELMB++ [7] – with improved radiation hardness and board flexibility, and removing previous weaknesses.

The ATLAS detector will undergo several upgrade stages for which new DCS components have to be designed and implemented. The first of these new projects is the DCS for an additional innermost barrel layer of the Pixel detector [8] which will be installed during the upcoming long shutdown in 2013/14.

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