The Power System Detector Control System of the Monitored Drift Tubes of the ATLAS Experiment

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Abstract

In this note the Detector Control System (DCS) for the power supply (PS) of the Monitored Drift Tube (MDT) chambers of the ATLAS experiment is presented. The principal task of DCS is to enable and ensure the coherent and safe operation of the detector. The interaction of the detector experts users or shifters with the detector hardware is also performed via DCS. This system monitors the operational parameters and the overall state of the detector, the alarm generation and handling, the connection of hardware values to databases and the interaction with the Data Acquisition system (DAQ).

In this note the Power System (PS) system as a Detector Control Subsystem is presented. Furthermore, it is outlined in detail what is the front-end to be controlled and how the architecture of the back-end is established.

I. Detector Control System in ATLAS Experiment

The work performed for the LEP experiments concerning the DCS, provided us with a useful and important experience and knowledge. On the other hand the implementation and integration of DCS in the LHC era, seems to be much different [1]. The basic change has to do with the introduction of new tools. The ATLAS Detector follows all the basic DCS guidelines of the LHC experiments, but in parallel, creates its own framework that facilitates the development and ensures further the homogeneity among the various ATLAS detector control subsystems.

A. Tools For Detector Control System

In the late 90-s, the four LHC experiments decided to set up the Joint Controls Project [2]. After a detailed investigation a decision was made to use the commercial PVSS-II [3] as the Supervisor Control and Acquisition System (SCADA) tool to construct the back-end control systems. The very next step was the integration of a software framework based on the chosen package, in order to integrate, sequence and automate the control process of the LHC experiments.

B. PVSS-II

The PVSS SCADA system provides the following main components and tools:

1. A run time database.
2. Alarm generation and handling.
3. Graphical Editor.
4. Graphical Parameterization tool connected to the structure of the database.
5. Scripting language following C syntax.
6. Drivers for the connection between the PVSS and hardware.

C. JCOP and ATLAS framework

Given the increasing constraints on manpower, as well as the evident similarity in technical requirements for controls amongst the experiments, the project should enable more efficient use of resources to be made. The JCOP framework is an integrated set of guidelines and software tools which is used by DCS developers during the implementation of their own control system application. The framework includes as far as possible all templates, standard elements and functions required to achieve an homogenous control system. The framework provides guidelines for

- Integration and development
- Organization of libraries, panels, scripts
- Naming convention (PVSS system, library and panel names)
- Look and feel conventions (panel size, trend display, colors)
- Programming (control script)

Besides the main functionalities given above, the JCOP framework supports its users with even more specific tools. Such tools can be used for DAQ (Data Acquisition) connection, access control or connection with databases. But the most important offer of this framework that should be underlined, is that this is the main component for the organization and automation of the DCS of the back-end system.

Finally, it should be mentioned that except of the JCOP framework described above, the central DCS team of ATLAS experiment has established a special ATLAS DCS framework [4]. This framework provides the DCS developers with extra conventions, libraries and software tools and keeps the hole ATLAS DCS project as coherent as possible.

II. MONITORED DRIFT TUBE (MDT) CHAMBERS AND THE POWER SUPPLY

A. The MDT chambers and the geometrical representation

The Monitored Drift Chambers (MDT) are the high precision tracking chambers of the ATLAS muon spectrometer. They are designed to operate reliably in a high rate and high background environment and to provide a good spatial resolution [5]. Each MDT consists of layers of drift tubes filled with a gas mixture of Ar:CO_2 $(93\% : 7\%)$. Each drift tube is constructed with a grounded metallic cathode cylinder and an anode wire, passing through its center, held at a positive potential. A charged particle passing through the tube ionizes the gas along its path. The resulting electron avalanche travels towards the wire, while the produced ions drift towards the cathode cylinder, generating a trigger pulse that is detected by the detector electronics.

The ATLAS Muon Spectrometer is composed of 1168 MDT chambers which is divided in two main regions, Barrel region, including 656 chambers, and the Endcap region, including 512 chambers, and two sides, side A and C with respect to the interaction point. The Barrel region (pseudorapidity $\eta < 1.2$) is formed of three concentric to the beam axis cylinders. They are positioned at a radii of about 5, 7 and 10 m. These cylinders are called layers and thus there is the Barrel Inner (BI) layer, the Barrel Middle (BM) layer and the Barrel Outer (BO) layer. Finally another useful geometric entity is the sector. The Muon Spectrometer is subdivided into 16 sectors around the ϕ coordinate[5].

In the endcap region (pseudorapidity $1.2 < \eta < 2.0$) every side is arranged in four vertical to the beam line disks at distances of about 7, 10, 14 and 21 meters from the interaction point. These disks are called again layers and thus there is the Endcap Inner (EI) layer, Endcap EE (EE) layer - for EE chambers, Endcap Middle (EM) layer and Endcap Outer (EO) layer. Endcap region like barrel is subdivided in 16 sectors [5].

B. Power Supply Hardware

The operating voltage for an MDT chamber is 3080 Volts. When LHC will reach full luminosity the maximum (depending on size and position) current requirement is about 0,7 mA [5]. One High Voltage channel supplies one chamber multilayer; each MDT chamber is divided into 2 multilayers. The Low Voltage required for the chamber electronics is 5 Volts. The signals coming from tubes are collected by the mezzanine boards [5]. Each mezzanine board processes signals coming from 24 tubes and requires 5V as an input voltage. The data coming from mezzanine boards are multiplexed in a digital board called CSM (Chamber Service Module). The CSM sends the data to be read out by the DAQ and needs 5V and about 1 A of current to operate too. One low voltage channel supplies in parallel two MDT chambers.

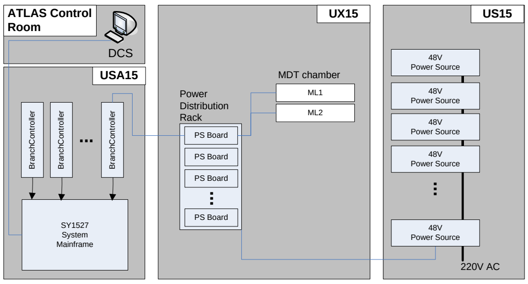

Figure 1: MDT power system architecture.

For the MDT DCS the architecture of the HV and the LV hardware system is the same. The MDT power system is composed by the CAEN SY1527 ethernet controlled mainframe along with the Embedded Assembly System (EASY) [6]. This system is divided in three parts (see Figure 1):

- The **power generator module**, is the module that supplies the power to the power distribution boards (see below). Its input line is the 220 AC line. It is located in US15 cavern of the ATLAS experiment and is remote controllable from the Power Supply DCS system.
- The **power distribution boards**, are the local power distributors to the chambers. These boards are divided into HV and LV modules (being radiation tolerant and magnetic field resistant) and are located in the UX15 cavern.
- The **controller module**, is the module connected to power distribution boards. It monitors all the channel parameters and alarms like voltage, current, trip, overvoltage. This module is located in the USA15 cavern mounted in a mainframe which is connected to the DCS PCs through ethernet. The communication of the hardware to the software is done via OPC protocol [7]. OPC (OLE -Object Linking and Embedding- for Process Control) is a software interface standard, that allows hardware to communicate with an MS-windows platform.

III. POWER SUPPLY PROJECT ARCHITECTURE

The amount of information exchanged between the hardware and the software demands a careful project architecture. This architecture incorporates the use of the computing power needed but also the internal organization of the DCS information inside each project.

A. Back-End Architecture

The back-end structure of Power Supply DCS of the MDT chambers is organized in abstract levels that are called stations. The first station, called Local Control Station (LCS) includes three machines. The first machine defines the first line of communication with the hardware. This machine houses the opc server as well as the opc clients that reads out the hardware values. The PVSS project of this machine is communicating with the PVSS projects of two more machines used for the PS control. One handles data from the Barrel Region MDT chambers while the other one handles data from the Endcap Region MDT chambers.

The Local Control Station of the PS DCS is connected to the next abstract level which is called Subdetector Control Station (SCS). This is a machine responsible for the whole MDT Detector Control Systems, including Gas, JTAG or Temperature DCS, etc. Through the SCS the project is connected to the top ATLAS DCS tree that is supervised from the top abstract level the Global Control Station machine as shown in Figure 2.

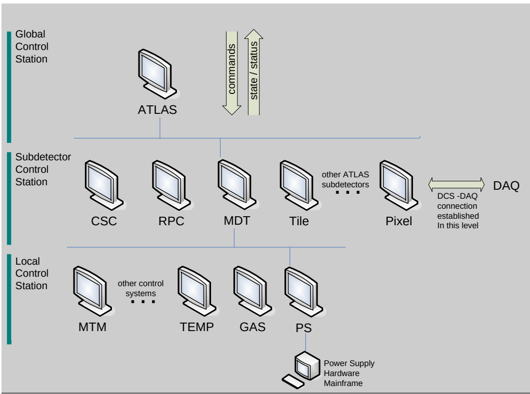

Figure 2: The overall ATLAS DCS architecture.

B. PVSS Project architecture

As soon as the communication between the hardware and the DCS projects is established, a careful organization of the data inside the project is vital. The PVSS package, has a very powerful concept for the handling of storage and the data, called ”datapoint”. The datapoint concept ensures consistent processing and at the same time also allows flexible adaption to specific problems. User authorizations, alarm handling , history configuration , smoothing procedures and many other useful applications make use of datapoints.

In the Power Supply structure, two main datapoint types are used. The first defined during the development of the project has to do with the information connected to a MDT chamber. This datapoint type is called ”fw_DUwithScript” and the datapoints themselves have the names of the chambers e.g. ”BIS1A02”. Under the chamber datapoint, there is the datapoint element of the ”.mapping” the ”.ML1”, the ”.ML2” and the ”.LV”

The ”.mapping” datapoint element, carries information about the mapping of the chambers' multilayer to the hardware channel. This information is a string that refers to the chain of the power distribution board the channel belongs to, the crate this board belongs to and the controller module this crate belongs to.

The ”.ML1”, ”.ML2”, ”.LV” datapoint elements have two other elements below, the ”.flags” and the ”.tripHdl”. The first element incorporates four boolean flags where in the case that one (or more of them) take the value ”TRUE” the channel is switched off and is left in that state. For example in case of a gas problem, the ”gasInterlock” flag is activated and the channel switch off, leaving the multilayer safe. The second element (”.tripHdl”) deals with trip handling and is used as a counter of trips happened in that multilayer and the trip recoveries applied after.

The second datapoint type used is called ”fwCaenChannel”. The structure of this datapoint type which structure is implemented from the JCOP framework and represents a Power Supply Channel.

IV. Finite State Machine

In the Detector Control Systems every ATLAS subdetector is treated as a finite state machine (FSM). This FSM is a modeling of the detector objects (parts or devices) where each object can have a finite number of states, transitions between these states and actions.

A. State and Status Concept

The DCS information of any node or any level and part of the hierarchy is decided from central ATLAS DCS and is propagated in two ways in parallel. The first piece of information refers to the *state* and the second one to the *status*. These two information routes, are distinct and supplement each other.

- The **State** information defines the operational mode of the system. (e.g. the chamber BIS1A02 is in state READY)
- The **Status** information gives an extra detail on how well is the system working in that particular state. (e.g. the chamber can be in state READY, but the status can be WARNING when reflects a temperature over the nominal value in a mezzanine card)

The concept of State and Status describes the project in more details. Moreover, another important attribute of this concept is the no-loss of the operational conditions. For example, let us suppose that a chamber is ramping up, an operation that can take up to 2 minutes, but during this time a reference voltage of its electronics declines from the nominal value. In this case the status information will carry the alarm information while the state will still be ramping up, giving this way a clear view of the shifter what actually is going on. There are four status names that are fixed and are used in all ATLAS subdetectors.

- *OK*: the system is working fine.
- *WARNING*: Low severity alarm, still the system can go on working.
- *ERROR*: High severity alarm, system has functionality problems.
- *FATAL*: Very high severity alarm, the system can not operate.

B. FSM Types

All devises, logical entities or partitions of the ATLAS detector are built from FSM ”units” that are called FSM types. In order to insert a device or a logical node in the FSM hierarchy you have to create first its prototype "unit". This "unit" is a set of FSM rules, state definitions, actions and color conventions. As soon as this prototype building block is ready, a name of the corresponding object is passed and then the FSM hierarchy is built. There are two different kinds of such units, the Device FSM and the Object FSM types.

C. FSM Device Types

The device types that usually represent the hardware inside FSM. For example a High Voltage channel, can have its own device type while a temperature sensor can have another device type. Nevertheless, in order to reduce the granularity and improve the performance, developers form a bigger entity like a chamber as a device unit. This device unit takes into consideration all the hardware that belongs to that chamber and sets the state and the status.

It is worth mentioning, the device unit, is the lower part of FSM, and deals directly with datapoints and PVSS script. On the other hand the Object types deal with the FSM rules based on SML language interacting with PVSS [1]. This language allows the detailed specification of objects, such as the state and actions and enables the finite state machine behavior of the objects inside the control system.

The name of the device unit type in Power Supply DCS project is **fw_DUwithScriptATL_MDTPS_CHAMBER**. This device unit that images a chamber, has nine different states:

- *ON* : The LV is ON and the HV is ON for both multilayers.
- *ON_50* : The LV is ON and the HV is ON for one Multilayer.
- *STANDBY* : The LV is ON and HV is OFF for both multilayers.
- *OFF* : LV and HV are OFF.
- *NO_LV* : HV is ON but LV is OFF.
- *RAMPING* : the LV is ON and the HV is Ramping Up or down.
- *UNKNOWN* : The chamber state is not defined; e.g. when the communication with the hardware is lost.

The finite state machine modeling of the power supply system, besides the states has actions too. For example if the device unit that represents a chamber is in a *STANDBY* state, the user has a set of actions to choose presented below:

- *SWITCH_LV_OFF* : Action to switch off LV, after this action the chamber is expected to be in state *OFF*.
- *SWITCH_HV_ON* : Action to switch on HV for both multilayers, after this action the chamber is expected to be in state *ON*.
- *SWITCH_ONLY_ML1_ON* : Action to switch on HV only for ML1, after this action the chamber is expected to be in state *ON_50*.
- *SWITCH_ONLY_ML2_ON* : Action to switch on HV only for ML2, after this action the chamber is expected to be in state *ON_50*.
- *RESET_TRIP* : Action to reset the trip of the chambers HV channel. The trip appeared when the channel is switched off but the Trip alarm remains. After this action, the trip alarm disappears.

The other states of the device units have their set of actions too. A MDT chamber is represented by this device unit so all the manipulation of the chamber is performed via these FSM actions.

D. FSM Object Types

The object types are types that represent logical objects or parts inside a FSM. These parts usually follow a geometrical segregation. For example a sector of the MDT chambers can be represented as an object type. Another important logical entity represented from object types are the partitions. Partitions inside the FSM are represented from the object type of partitions.

In detail, in the PS project there are:

- The **MDT_SECTOR_PS** object type that represents the sectors as logical objects. This object type defines the state of the sector according to the state of its children - its chambers.
- The **MDT_PARTITION_PS** object type that represents the partitions as logical objects. This object type defines the state of the partitions according to the state of their children - their sectors.
- The **ATLAS_STATUS** object type that propagates the information for all the various nodes of the hierarchy. The ATLAS_STATUS object is the same for both the sector and partition level.

E. FSM transition diagrams

State diagrams are a graphical representation of finite state machines. These diagrams (Figure 3) are useful during the development of the finite states machine making the code transparent among various FSM developers

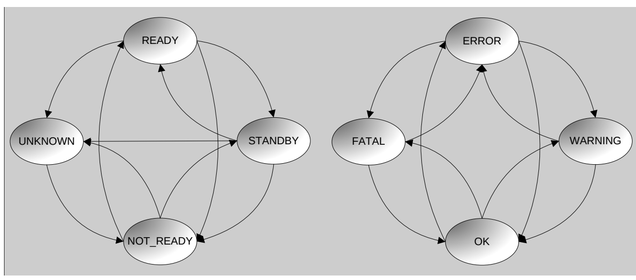

Figure 3: The FSM transition diagram for the object type (left) and the status object (right) of a MDT partition.

V. Alarm Handling

The MDT Power Supply DCS project deals with the hardware for the power supply of the chambers. One very important role of the project is the propagation and handling of various alarms coming from the hardware. These alarms, according to their severity, can be used from preventive actions to activating interlock procedures.

A. Channel Alarm

Usually an alarm of the Power Supply system comes from the power supply channel itself. One channel is responsible for the supply of one MDT multilayer. All the information concerning the state of a channel comes from a single OPC item, called *status*. This can be achieved because this item has a special 16 bit pattern indicating the channel status as shown in Table 1

Table 1: Bit assignment

(0) ON/OFF	(1) Ramp Up
(2) Ramp Down	(3) Overcurrent
(4) OverVoltage	(5) UnderVoltage
(6) External Trip	(7) Over HVmax
(8) External Disable	(9) Internal Trip
(10) Calibration Error	(11) Unplugged
(12) UnderCurrent	(13) OverVoltage Protection
(14) Power Fail	(15) Temperature Error

Leaving out the first three bits that deal with the information about the operational state of the channel, the rest are connected with alarms. For Example, if the bit 9 is raised this means that the channel tripped, which is an indication of bad gas flow in the multilayer. All these alarms belong to the alarm classes such as warning, error or fatal according to their real severity.

B. Board Temperature Alarm

One other alarm item, provided directly from the power supply boards, is the *board temperature alarm*. The boards are equipped with a temperature sensors expressed in degrees Celsius. Due to the importance of this alarm, there are two levels of interlock actions taken on the board. The first temperature check is done in the software level. The project continuously monitors these temperature values and in the case of an alarm an interlock mechanism is activated switching off the power supply. Furthermore, a hardware interlock mechanism is implemented to protect overheated boards.

C. Alarm Screen

The alarm screen is a self-contained panel for the display of all various alarms that can occur in the detector. This screen is of great importance and the first to look in case of any abnormal response. The alarms contained can be filtered in various ways according always to the importance and the user needs. The alarm screen in parallel with the ATLAS DCS Operation interface (OI) are the two active interfaces that the DCS user needs in order to operate the experiment from the DCS side point of view.

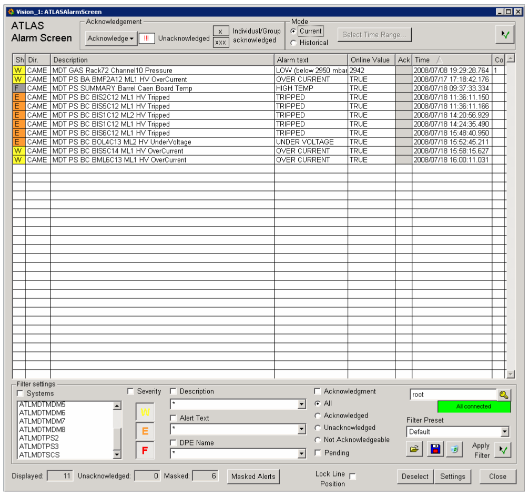

Figure 4: The alarm screen for the MDT system during a combined detector cosmic run.

In Figure 4 a screen shot of the MDT alarm screen freezed during a cosmic run is shown. One alarm comes from the Gas system while all the rest come from the Power Supply system. The description column is the most important column that gives the details of these alarms. For example, there is the *MDT PS BC BIS2C12 ML1 HV Tripped* alarm. This informs the shifter that in chamber BIS2C12 (belongs to partition Barrel C) of the system PS got a trip alarm in ML1. This alarm perhaps has to do with a defective power supply channel or with a real problematic camber multilayer. In any case, this alarm handling propagates the information to the shifter/expert in order to take the appropriate action.

VI. Configuration Databases

The MDT PS DCS project is also connected to a configuration DataBase (DB). This DB is responsible for the storage of the device properties (e.g. trip current limits, trend smoothing details, archiving configuration) and settings (e.g. alarms ranges, output values, operational voltages). The PVSS project uses a tool that is developed from the JCOP framework, called ”configuration DB tool”.

The concept of recipes is the main idea behind the configuration DB tool. The recipes are a set of predefined settings under one name - the recipe name. The DCS expert, in collaboration with the detector experts, gathers all the appropriate settings that characterize the state of the detector (at least from the Power Supply side of view) and creates a recipe with a meaningful name. This recipe is saved in DB and is ready to be used by the shifter. The panel, Figure 5, is the interface to the configuration DB. The shifter can choose one of the predefined recipes from a drop down list. Moreover, this interface, allows us to create a new recipe, under the name ”custom”. In this case the user can choose a set of chambers to apply the new settings with their corresponding values. The configuration DB tool is powerful enough to ease the detector manipulation from DCS side, while at the same time ensuring coherency and safety.

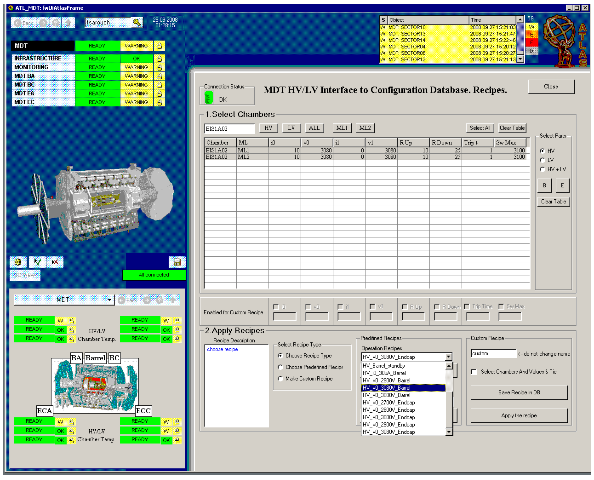

Figure 5: Configuration database.

VII. Operation Interface

A main care of ATLAS DCS is to offer an effective way for the OI of the numerous subdetectors/subsystems of the ATLAS experiment. All the relevant DCS information is organized in a single screen window. This interface is equipped with a navigation tool that lets the user navigate through all the DCS data that come from these different subdetectors/subsystems and are displayed in panels as shown in Figure 6.

A. ATLAS DCS Navigation Buttons

In order to reach easily and quickly any part of the control hierarchy a navigation facility is been integrated within the OI. This navigation tool is shown at the top left of the screen. It consists of four self-explained buttons: "backwards", "forwards", "home" and "go up one level", that allow the navigation to the control node that one is interested to monitor or to take action.

B. ATLAS DCS Main Panel

This is the panel which provides the user with all the basic information concerning the workspace chosen previously with the navigation tool. From this panel the user can see the DCS data in various forms like: numbers, bar trends, tables, plots or geographical representations of the subdetector with the appropriate state connected DCS colors.

C. ATLAS DCS Secondary panel

This is a second small panel, shown at the bottom left and provides information for the chosen workspace. This panel provides a navigation tool so one can use it to find supplementary information parallel to the one supplied form the main panel.

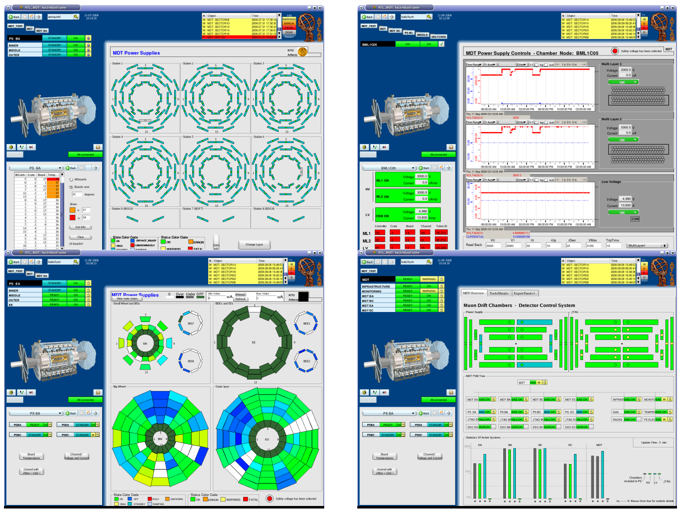

Figure 6: Various screens shots of the MDT PS project.

VIII. Conclusion

The low and high-voltage Detector Control System of the ATLAS Monitored Drift Tubes is presented. Both voltage systems follow a common architecture. The developed system has been successfully used during the commissioning and integration phases of the muon spectrometer. It is ready for the LHC data taking.

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