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Detector Control System of Tile Calorimeter Low Voltage Power Supplies System

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Abstract

This paper describes the development and implementation of the Detector Control System (DCS) of the Low Voltage Power Supplies (LVPS) of the Tile Calorimeter detector. The DCS must ensure coherent and safe operation of the LVPS system, which is one of the main systems of Tile Calorimeter. It provides control and monitoring of all parameters of the system and gives to the user a comprehensive picture of the detector behavior.

1 Introduction

The Tile Calorimeter [1] is one of the sub-detectors of the ATLAS experiment [2] [3]. It is a sampling calorimeter made of steel plates (absorber) and scintillating tiles (active material). The design, general features and expected performance of the Tile Calorimeter are well described in [1]. The Tile Calorimeter consists of one barrel and two extended barrel parts. All the three sections have a cylindrical structure further sub-divided into 64 independent modules. The calorimeter cells are defined by grouping together sets of optical fibers into bunches leading to photomultiplier tubes (PMTs). The front-end electronics and PMTs are located in the outer section of the Tile Calorimeter modules, in so-called electronics drawers.

The Detector Control System (DCS) is responsible for safe and coherent detector operation. All ATLAS sub-detectors have their own local DCS, whose detailed architecture depends strongly on the structure of the general DCS system of the ATLAS experiment and on electronics architecture and mechanical issues of the sub-detector itself. Each local DCS controls and monitors the operation of a sub-detector and related equipment.

Although each sub-detector is responsible for the implementation and for internal organization of its sub-systems, it must fully comply with the requirements defined by ATLAS central DCS [4]. The DCS of the sub-detectors must follow the general ATLAS DCS system architecture as much as possible unless there are special requirements where the sub-detectors need tailored solutions.

The DCS provides control and monitoring of the main systems of the Tile Calorimeter detector, which are the High Voltage distribution system and the Low Voltage Power Supply (LVPS) system. In addition, DCS is responsible for communications with detector calibration and data acquisition systems, and monitoring the detector infrastructure related systems: detector water-cooling and rack control.

2 Back End system of the Tile Calorimeter DCS

The commercial Supervisory Control And Data Acquisition (SCADA) package PVSS II has been chosen by the Joint COntrols Project (JCOP) at CERN to implement Back End (BE) software for all LHC experiments [5]. It is used to connect to hardware devices, acquire data from them, monitor their behavior and to initialize, configure and operate them. PVSS II has a highly distributed and flexible architecture, and it allows connection of several autonomous systems via the network.

The BE system of the ATLAS experiment is organized hierarchically in three layers or levels as shown in Figure 1. This hierarchy allows the experiment to be divided in independent partitions, which have the ability to operate in standalone or integrated mode.

At the top layer, there are Global Control Stations (GCS), which are in charge of overall operation of the detector. They provide high level monitoring and control of all sub-detectors, while data processing and command execution are handled at the lower levels. The GCS is available to access all stations in the hierarchy. The Sub-detector Control Station (SCS) represents the middle level of the hierarchy. The Tile Calorimeter, as a sub-detector of ATLAS, has its own SCS, which allows the complete operation of the sub-detector, by means of dedicated graphical interfaces. At this level of hierarchy, the connection with the TDAQ system, calibration systems and detector infrastructure takes place in order to ensure that detector operation and physics data taking are synchronized. The bottom level of the hierarchy is made up of Local Control Stations (LCS), which handle the low level monitoring and control of LV and HV systems of the sub-detector. The LCS executes the commands received from the layers above.

In order to implement the BE system of the Tile Calorimeter DCS, five rack-mounted computers are used, located in racks in the ATLAS electronics area underground (USA15). As it is shown in Figure 1, four of those are used as LCS stations (each for one Tile Calorimeter partition) and one as the SCS station. The operating system of those computers is Windows XP and they run PVSS II as a system service.

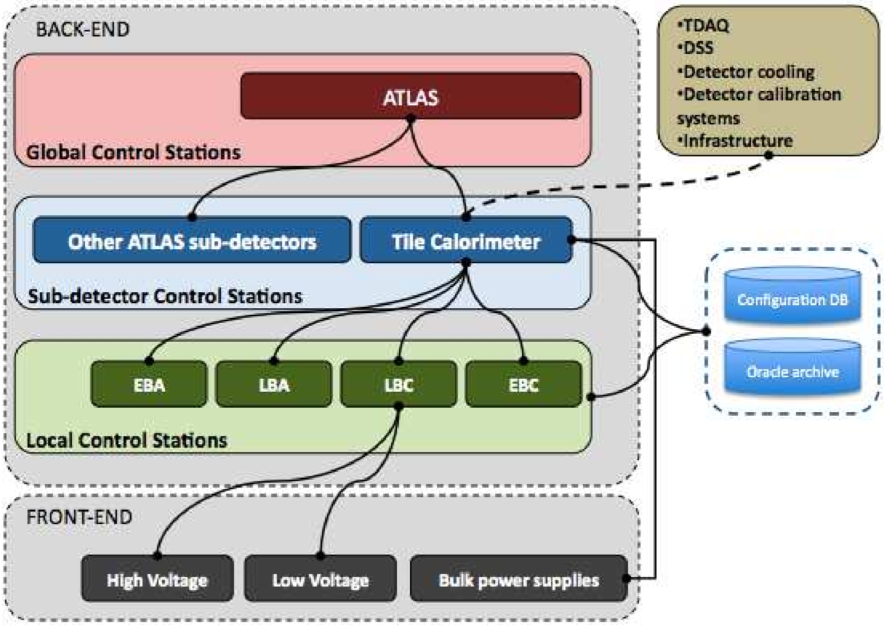

Figure 1: Hierarchy of the DCS of the Tile Calorimeter, as part of the ATLAS control system

3 The Low Voltage Power Supplies (LVPS) System

The LVPS system is a two stage system: the first stage converts 400V AC input into 200V DC output in USA15 and then the second stage placed on the detector converts 200V DC into 8 independent levels of lower voltages in the range (-15V; +15V) used to power the detector Front End (FE) electronics (the digital and analog components of the readout system and High Voltage (HV) distribution system). In this section, the hardware entities of the LVPS system and their interconnections are briefly described.

3.1 Description of the device units of LVPS system

The LVPS system is composed of three devices: finger Low Voltage Power Supplies (fLVPS) located at the FE electronics of the Tile Calorimeter, auxiliary boards (AUX boards) located in racks in USA15 and bulk power supplies providing 200V DC located also in the racks of USA15.

200V Bulk Power Supply (200V PS) - uses 400V AC input and produces 200V DC output, which is used as an input to the fLVPS devices. The 200V PS devices are located in racks in USA15. Each unit has 3 output channels and each channel feeds four fLVPS. The nominal output voltage from a channel is 200V, with nominal consumption of 4A and 5A for the FE electronics of the Extended and Long Barrel of the Tile Calorimeter, respectively (maximal output current 8.5A).

Finger LVPS (fLVPS) - is a DC-DC converter device, located at the Tile Calorimeter FE electronics. It uses 200V DC as input and converts it into eight different output voltages, from 3.3 to ± 15V, with a maximum fluctuation of $< 0.01\%$. Eight DC-DC converter bricks placed inside this device are grouped into two groups. One group supplies the PMT high voltage distributor system, while the other feeds the rest of the FE electronics. Those two sets of DC-DC converter bricks are called LV-MB and LV-HV side bricks. The list of individual DC-DC converter brick names, together with their operational output ranges, is given in Table 1.

DC-DC converter bricks	V out range [V]	I out range [A]
LV-MB bricks		
3.3VDIG	3.3 - 3.9	1.7 - 5.6
5VDIG	5.0 - 5.9	3.3 - 6.7
5VMB	5.0 - 5.9	6.6 - 13.3
-5VMB	5.0 - 5.9	3.3 - 6.7
15VMB	14.4 - 15.65	0.2 - 0.6
LV-HV bricks		
5VHV	5.0 - 5.9	0.1 - 0.3
15VHV	14.4 - 15.65	0.15 - 0.4
-15VHV	14.4 - 15.65	0.15 - 1.9

Table 1: List of DC-DC converter bricks of the fLVPS device and ranges of their voltages and currents output

Auxiliary board (AUX board) - provides operational voltages for each fLVPS device and switches off its output voltages by disabling current loops. The AUX board has four sets of output voltages and current loops, each dedicated to one fLVPS device and one more interlock current loop. The AUX board output voltages and currents are summarized in Table 2 and its connection to other LVPS system devices can be seen in Figure 2. The purpose and functionality of the AUX boards are the following:

- To provide power for the Analog input (Ai) part of the ELMB (see Section 4.2) and its mother board placed inside the fLVPS device. (The separate power line for ELMB gives the possibility to power cycle it in case of readout problems without disturbing supply to the FE electronics).
- To provide two current loops per fLVPS, which enable or disable output voltages separately for LV-MB or LV-HV sets of DC-DC converter bricks.
- To provide a short (∼1 sec) start-up pulse to switch on the DC-DC converters. When the DC-DC converters start to produce output voltage the start-up pulse is no longer needed.
- To produce current loops for the LVPS system hardware interlock (hardware interlocks are not discussed in this note, since they do not belong to the DCS system)

The total number of the LVPS system device units, used for the Tile Calorimeter are the following: 256 fLVPS, 64 AUX boards and 22 units of 200V Bulk Power Supplies.

3.2 Schematics of interconnection of LVPS system devices

This section briefly describes the schematics of the connections between the devices of the LVPS system for powering purposes. As it is shown in Figure 2, there are long supply lines from the ATLAS electron-

Channel	V out [V]	I out [mA]
Supply for ELMB Ai (of fLVPS)	12	30
Supply for MB (of fLVPS)	12	30
Start-up pulse	12-18	30
LV-MB current loop	–	10
LV-HV current loop	–	10

Table 2: List of output voltages and currents of AUX board devices

ics cavern to the detector of the order of 120-150m. Those supply lines are used to provide necessary voltages for operation of the fLVPS devices.

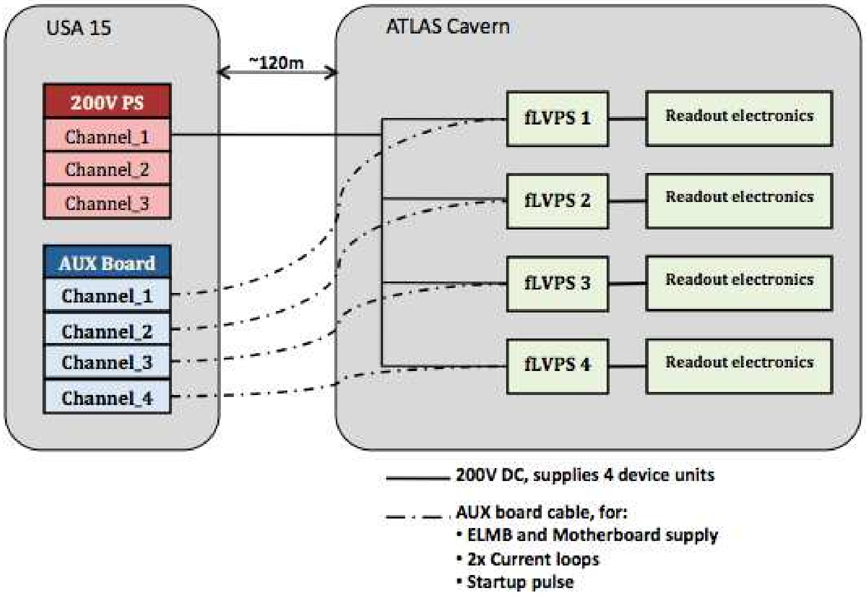

Figure 2: Schematics of supply cables interconnection in LVPS system

The AUX board has four channels, each of them is connected to a single fLVPS device, i.e. one AUX board supplies a sequence of four fLVPS devices. Similarly, each of the three channels of a 200V DC bulk power supply feeds four fLVPS devices with DC power.

4 Communication schemas and types of LVPS system devices

The communication protocols used in the LVPS system and hardware connections between DCS computers and controlled devices are briefly described in this section. Devices of the LVPS system support two different types of communication protocol: for 200V PS devices the serial Modbus [6] communication is used; for readout and control of AUX boards and fLVPS devices the CANbus [7] protocol is used.

4.1 Communication with 200V PS

PVSS II provides a driver for the TCP variant of the Modbus protocol. The power supply side supports the serial Modbus/RTU protocol. In order to interface the 200V PS device with SCADA software in a flexible way, an intermediate device was incorporated as a part of DCS. It acts as the converter of Modbus/TCP to Modbus/RTU and as is shown in Figure 3. Communication with the 200V Bulk PS can be established through the TCP/IP network. In this way the PC connects to the device through the Ethernet card.

As an intermediate device, the Port Server TS MEI was chosen [8]. It is a commercial product, designed for universal and high-performance serial-to-Ethernet connectivity. It is ideal for RS 422 applications where remote device management and control are required.

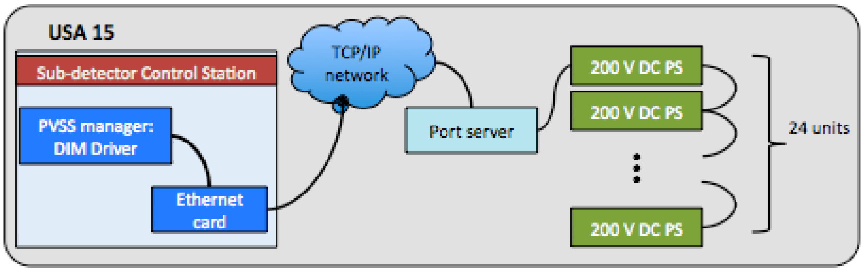

Figure 3: 200V Bulk PS communication schema

As it is shown in Figure 3, communication with 200V PS device units is established from the SCS (see chapter 2 and Figure 1). For the Tile Calorimeter sub-detector, the total number of 200V PS device units to be controlled is 22. These power supplies are daisy chained and connected to the port server.

The mapping of addresses between PVSS II and the 200V PS device units is defined in the configuration of the PVSS II Modbus driver, where the 200V PS device units are interpreted by the PVSS II as the Programmable Logic Controllers (PLC). Table 3 shows the parameters of Modbus driver, defined in the project running at the SCS. The node addresses of the device units are set manually directly on the front panels of the device units.

Parameter	**Value**
PLC	_Mod_Plc_[PLC No]
PLC number	11...16; 21...26; 31...36; 41...46
Unit address	11...16; 21...26; 31...36; 41...46
Modbus transaction timeout	10 sec
Frame coding	TCP
Endianity	Big Endian
List of Hosts	IP address of Port Server

Table 3: Communication properties of Modbus/TCP driver

4.2 Communication with AUX board and fLVPS devices

The fLVPS and AUX board devices make use of the Embedded Local Monitoring Board (ELMB) [9], as a general purpose I/O and processing unit for CAN communication. The ELMB fully conforms to the industry standard of CANbus protocol and it provides the minimal functionality of a slave node according to the specification of this protocol. The configuration of the Analogue-to-Digital Converter (ADC) used in the ELMBs in the LVPS system is given in Table 13 in appendix A.

Figure 4 shows the layout of the ELMB based readout chain, for one Tile Calorimeter partition. In the LVPS system the maximum number of ELMB nodes per CAN branch is 16 and the number of the CAN branches per partition is 5. Four of the CAN branches are used for communication with fLVPS devices and one for communication with the AUX boards. The CAN Power Supply Unit (CAN PSU) is used to feed the CAN Transceiver part of the ELMB. The length of the CAN branches, used to communicate with the fLVPS devices, is 120-150m and for the AUX board devices it is ∼10m.

The CAN communication speed for the AUX board and fLVPS devices is set to 125KB/sec. Used CAN node addresses are from 1 to 16, as labeled in Figure 4. Branch #0 serves for the communication with the AUX devices and the branches #1 - #4 for the fLVPS devices. The numbering of Kvaser card port corresponds to the branch numbering.

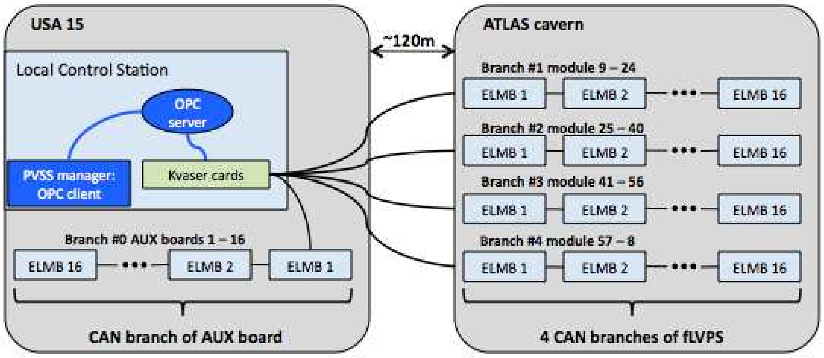

Figure 4: Communication schema with AUX boards and fLVPS devices (for one Tile Calorimeter partition)

To interface the ELMB based FE systems with the back-end SCADA software PVSS II, dedicated middle-ware software was developed by the ATLAS DCS central team, the CANopen OPC server [10], which is based on OPC [11] standards. A dedicated OPC client is provided by the PVSS II manager.

The OPC server is used to acquire raw data and to send commands to the devices. It does the conversion of raw data to the physical units (to voltages, currents and temperatures). The OPC configuration file (OPCCanServer.cgf) contains the information needed to define the address space of the OPC server and formulas for conversion of the acquired raw data to the physical units (voltages, currents and temperatures).

Below, two standardized CAN communication objects are summarized and their relevance to the detector control outlined:

- Process Data Objects (PDO) are broadcast and unconfirmed messages containing up to 8 data bytes. This mechanism is used for real-time transfers, with one sender and one or more receivers. The PDO messages are used for monitoring purposes.

- Service Data Objects (SDO) are confirmed transfers of any length. Peer-to-peer communication is established between two nodes of the network by this mechanism. The SDO messages are used to transmit configuration commands to ELMBs.

The Analog inputs (Ai) to the ELMB (i.e. monitored parameters of the fLVPS and AUX board devices) can be read out using PDO messages. The so-called SYNC command triggers the ELMB to start the Ai channel scan and to send out up to 64 PDO messages, one for each analog input channel. With an ADC frequency of 60 Hz it takes ∼1-2 sec to scan all the ELMB Ai channels, see more details in appendix A.

SDO messages are used to transmit commands to the ELMBs of the fLVPS and AUX board devices. The list of implemented commands for fLVPS and AUX board devices are given in Table 4, together with the respective CAN object properties. For the AUX board commands on the $Start-up$ pulse, the set of values in last column define the width and amplitude of the generated pulse. For the fLVPS device, the output voltages are adjusted by the values whose allowed ranges are given in the last column. Commands to the fLVPS and AUX boards via the respective ELMBs are processed in the following way:

- **AUX boards -** by sending SDO messages to the ELMB, the DAC registers of the Maxim 6957 chip can be accessed in order to trigger actions that are defined by the CAN object index. The Maxim chips are located on the Motherboard of the AUX board. The ELMB has access to the Motherboard of the AUX board through its Serial Peripheral Interface (SPI).

- **fLVPS -** by sending SDO messages to the ELMB, the DAC registers of the Maxim 525 chips located on the Motherboard of the fLVPS device can be accessed. The output voltages of individual DC-DC converter bricks can be adjusted by writing the appropriate values in the DAC registers, via the Digital output (Do) of ELMB.

AUX board channel	**Command**	**CAN object index**	**Value(s) to send**
ELMB supply	ON/OFF	2701/2702H (0)	0x04010N
ELMB-MB supply	ON/OFF	2701/2702H (0)	0x07020N
MB current loop	ON/OFF	2701/2702H (0)	0x4F040N
HV current loop	ON/OFF	2701/2702H (0)	0x4F050N
Start-up pulse	Set width	2700H	0x0 - 0x12
Start-up pulse	ON amplitude	2705H	0x0 - 0x7
Interlock current loop	ON	2704H	0x2F
fLVPS channel			
Digitizer 3.3	Set min-max	6411H (1)	4095 - 0
Digitizer 5V	Set min-max	6411H (2)	4095 - 0
Motherboard 5V	Set min-max	6411H (3)	4095 - 0
Motherboard -5V	Set min-max	6411H (4)	4095 - 0
Motherboard 15V	Set min-max	6411H (11)	4095 - 0
HV supply 5V	Set min-max	6411H (12)	4095 - 0
HV supply 15V	Set min-max	6411H (13)	4095 - 0
HV supply -15V	Set min-max	6411H (14)	4095 - 0

Table 4: List of commands and parameters that can be send to the ELMBs of the AUX boards and fLVPS. (The Set width and Initialization of AUX board are equivalent commands see section 5.3).

On the CANbus, PDO messages have higher priority than SDO messages, as defined by the arbitration collision mechanism of the CANbus protocol. In order to avoid delays (or possible timeout) of SDO messages, the ELMBs that should receive an SDO message are first set into pre-operational mode. In the pre-operational mode the ELMB stops sending out PDO messages and becomes available to receive SDO commands.

5 Monitoring and Commands for LVPS system devices

The DCS of the Tile Calorimeter provides constant monitoring of the LVPS system parameters and provides comprehensive information about the detector behavior. Critical parameters of the system are always checked to see if they are within allowed range, otherwise WARNING or ALARM are triggered.

5.1 Monitoring of 200V PS devices

The parameters of the 200V PS are monitored at intervals of 20 sec. This time interval can be defined separately for each Poll group (one per device unit). For monitoring, all the read only registers are polled, which include all the ones used for Input Status and Input Register.

The number of monitored parameters per device unit is 44, where 42 of them characterize individual output channels (3 channels per device unit) and the rest describe the Power Supply global parameters. Table 5 shows the monitored parameters of the 200V PS devices, together with their output ranges.

Temperature probes are located at each output channel of the 200V PS device. A dedicated PVSS II script averages the values read out from the temperature probes of one device unit and triggers WARNING or ALARM if the temperature is outside the allowed range. Additionally, the script marks channel trips, as the power supplies have no dedicated register for this.

Parameter	**Range**
Crate On/Off Status	0: Off; 1: On
Crate remote control	0: Disabled; 1: Enabled
3x Channel Output	0: Off; 1: On
3x Channel Mode	0: Manual; 1: Automatic
3x Channel On/Off Status	0: Off; 1: On
3x Channel Error Status	0: OK; 1: Hardware Error
3x Channel Over Voltage	0: OK; 1: Over Voltage
3x Channel Over Current	0: OK; 1: Over Current
3x Channel Fuse	0: OK; 1: Error
3x Channel Status	0: Offline; 1: Online
3x Channel Interlock	0: Open; 1: Close
3x Channel HW error	0: OK; 1: Error
3x Channel Output voltage (V)	1 ... 2500 (*0.1 Volt)
3x Channel Output current (I)	1 ... 1000 (*0.001 Amp)
3x Channel Sense line voltage (V)	1 ... 2500 (*0.1 Volt)
3x Channel Temperature	1 ... 900 (*0.1 Celsius)

Table 5: Monitored parameters per 200V PS device unit, together with respective output ranges

5.2 Monitoring of AUX board and fLVPS devices

Parameters of the AUX board and the fLVPS devices are readout at a frequency that is defined in the configuration of the OPC server, and the default value that was chosen is 10 seconds. By sending SYNC commands to the CANbus branches, the OPC server gets data from the ELMBs at intervals of 10 sec.

The ELMB has 64 Ai channels and digitizes analog signals at a frequency of 60 Hz (see Table 13 in appendix A). The AUX board uses only 37 Ai channels of its ELMB and the fLVPS uses only 55 Ai channels. In other words, 37 parameters are read out from the AUX board device and 55 from the fLVPS device. The number of the LVPS system parameters per partition acquired through the OPC server and processed by the PVSS II every 10 sec is 4112.

Critical parameters of the AUX board and the fLVPS devices are further analyzed by the PVSS II data-point functions and control scripts, where pre-defined thresholds are used to trigger WARNING or ALARM. Tables 6 and 7 show the list of monitored parameters of the AUX board and the fLVPS devices, together with the associated ELMB channels and allowed ranges.

Channel	**Allowed range**
(4x) Temperature probes	$>$ 60/70 (^{o}C) : Warning/Alarm
(4x) ELMB voltage	$>$ 10 (V) : OK
(4x) ELMB current	$>$ 25 (mA) : OK
(4x) MB voltage	$>$ 10 (V) : OK
(4x) MB current	$>$ 25 (mA) : OK
(4x) Start-up pulse voltage	-
(4x) Start-up pulse current	-
(4x) MB current loop	$>$ 7 (mA) : OK
(4x) HV current loop	$>$ 7 (mA) : OK
Interlock current	$>$ 25 (mA) : OK

Table 6: List of AUX board channels, together with the associated ELMB Ai channel. The most relevant allowed ranges are shown. The thresholds for temperature warnings/alarms are applied to the averaged measurement of all four probes

5.3 Implemented commands for LVPS system devices

The DCS of the LVPS system provides a comprehensive set of commands in order to operate the system and to provide correctly the low voltage for Tile Calorimeter FE electronics. Properties associated to the commands implemented for devices of the LVPS system are described in this section. The command libraries were written in the PVSS II programming language.

200 V DC PS commands:

- **Crate Local Control -** Enables or disables local control of the Power Supply
- **Channel ON/OFF -** Switch ON/OFF channel of 200V PS
- **Set voltage -** Set output voltage

Channel	Allowed range
3V Brick input voltage	-
(4x) ±5V Brick input voltage	-
(3x) ±15V Brick input voltage	-
3V Brick input current	-
(4x) ±5V Brick input current	-
(3x) ±15V Brick input current	-
3V Brick output voltage	2.5 - 3.6 : OK
(4x) ±5V Brick output voltage	4.5 - 5.8 : OK
(3x) ±15V Brick output voltage	13.15 - 14.5/14.8/15.5 : OK
3V Brick output current	-
(4x) ±5V Brick output current	-
(3x) ±15V Brick output current	-
3V Brick sense line voltage	-
(3x) ±5V Brick sense line voltage	-
15V Brick sense line voltage	-
(2x) Water temperature probes	-
(16x) Brick temperature probes	> 50/60 Warning/Alarm

Table 7: List of the fLVPS device parameters. The most relevant allowed ranges are shown (the upper limit of 15V Bricks varies from 14.5 to 15.5). The sense lines are not implemented for all types of output voltages.

- **Set current limit -** Set limit on output current
- **Set high/low sense limit -** Set high/low limit on sense line voltage measurement

AUX board commands:

- **Initialization -** sets the width for the Start-up pulse (see section 2). With this command the device AUX Board goes to its initial state, i.e. all output channels are switched OFF and becomes ready to accept commands via CAN bus.
- **Channel ON/OFF -** to switch ON/OFF any output channel of the AUX board device (see list of output channels in Table 2).
- **Partition recover -** takes an action on all AUX board devices of one partition. It sends the *Initialization* command to un-initialized AUX boards and switches ON the ELMB and the MB supply channels of all AUX board devices.

fLVPS commands:

- **Set output voltage -** sets output voltages of individual output channels, within allowed ranges. The DAC constants are in inverse correlation with output voltages, i.e. minimum DAC constant corresponds to maximum output voltage.
- **Switch on fLVPS -** enables output voltages from fLVPS devices. During this action several commands are sent to the ELMBs of the fLVPS and AUX board devices, in the sequence described in Table 8.

At step 8 shown in Table 8, a time delay is implemented in order to ensure stabilization of output voltages from fLVPS device and only after that the output voltages are tuned to nominal values.

	Command/action	Time delay
1.	Check communication with the ELMB of fLVPS	-
2.	Load Calibration constants from Configuration DB	-
3.	Set output voltages to minimum	Wait for the ELMB reply
4.	ON HV-LV current loop	-
5.	ON Start-up pulse	3 sec
6.	ON MB-LV current loop	-
7.	ON Start-up pulse	3 sec
8.	Stabilization time	40 sec
9.	Ramp-up output voltages to nominal	5 sec

Table 8: Queue of actions taken during switch on of a fLVPS device. Some of the actions cause significative time delays as shown.

5.4 Sequence and synchronization of commands

In this section we describe the sequence of actions (commands), which should be followed in order to provide low voltage for the Tile Calorimeter FE electronics. This sequence of actions is defined by the hardware configuration of the LVPS system devices. Table 9 shows the sequence of commands in their right order of execution and time estimates for their execution.

	Command	Time per partition
1.	Partition recover	$\sim$ 1 min
2.	Switch ON 200V PS channels	$\sim$ 1 min
3.	Switch ON fLVPS output channels	$\sim$ 12 min

Table 9: The switch on commands of the different components of the LVPS system in the correct sequence and estimated time for their execution

The DCS commands can be launched either at the level of single device units or at higher levels using actions implemented at the Finite State Machine (FSM) [12] on a sub-detector module, partition or detector. On the level of a single device unit, it takes $\sim$1 min to power-up to nominal output voltage one fLVPS device unit (including stabilization time). At higher levels, commands are executed in parallel for multiple devices.

Synchronization of commands becomes necessary at the point when commands to different devices, connected through the same or different CAN branches, should arrive one after another within hardware specific time delays. Such a situation appears during the command Switch ON fLVPS, between steps 3 - 7 described in Table 8. In order to avoid possible conflicts of SDO/PDO messages, and to avoid delays in command delivery, the synchronization mechanism is implemented on the level of PVSS II functions. In other words, on each CAN branch, SDO messages can be sent only to one device unit at a time.

6 Usage of Configuration and Conditions DB

Two types of databases are used in the Tile Calorimeter DCS - Configuration and Conditions databases. The Configuration database is used to store the data related to the detector configuration. The Conditions database is used to store information for understanding the detector behavior, such as voltages, currents and temperatures of devices.

6.1 Configuration DB

The Configuration DB is used to store the output voltage calibration parameters and the DAC parameters that correspond to the nominal output voltages of the fLVPS devices:

- **Calibration parameters -** are used to correct output and sense line voltage measurements from the fLVPS, using tests performed at the laboratory. These constants are applied at the PVSS II software level, using the message conversion mechanism of data-point elements. The distribution of the currently used calibration constants is given in Figure 5.
- **DAC parameters -** numbers to be sent to the fLVPS device in order to set nominal output voltages.

At the assembling location, the fLVPS devices are tested and certified, which includes finding calibration and nominal DAC settings for output voltages. Calibration and DAC parameters are saved in the Configuration DB, together with the serial number of the ELMB of the tested fLVPS device. The serial number of the ELMB is unique and used to find calibration and DAC constants for the appropriate fLVPS device in the Configuration DB. During operation at the detector, the DCS uses the serial number of the ELMB to load calibration and DAC parameters of the appropriate fLVPS device from the Configuration DB.

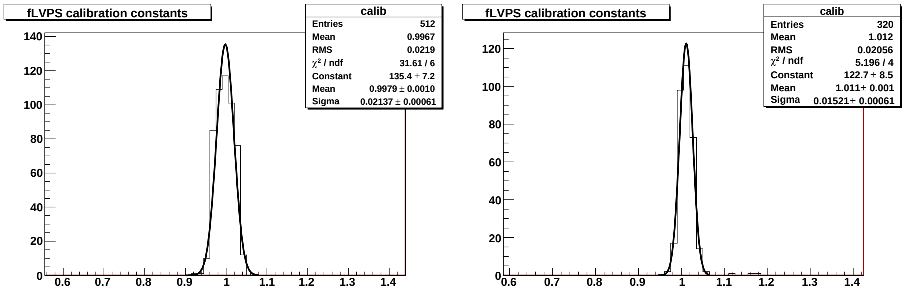

Figure 5: Distributions of calibration parameters for measured output (left) and sense line (right) voltages, for all fLVPS of one of the Tile Calorimeter partition

6.2 Conditions DB and data smoothing

The DCS acquires data from the fLVPS and the AUX board devices every 10 sec, and from the 200V Bulk PS every 20 sec. However, in stable detector working conditions most of the DCS data changes very little with time and there is no need to save all this data into the database. In order to save disk space and bandwidth, and allow faster access to the data, a smoothing filter is applied to the DCS data. There are several types of smoothing applied for saving LVPS system parameters into the database, and they work in the following way:

- **Threshold and Time -** makes a comparison between old and new data and does not save it into the database if the difference is smaller than a pre-defined threshold. Data will be saved in any case after a given time interval

- **Old/new and Time -** makes comparison between old and new data, and does not save it into the database if data remains unchanged. Data will be saved in any case after a given time interval.

Tables 10 - 12 list the parameters archived for the devices of the LVPS system (200V Bulk PS, AUX board and fLVPS) together with the types of smoothing and their parameters.

Parameter	**Smoothing type**	**Time (sec)**	**Threshold**
Input voltages	Value and time	3600	± 1 V
Input current	Value and time	21600	± 0.2 A
Output voltages	Value and time	3600	± 0.05 V
Output current	Value and time	3600	± 0.05 A
Temperature	Value and time	3600	± 1^oC
DAC constants	Old/new and time	21600	-
State	Old/new and time	21600	-

Table 10: Smoothing settings of the archived parameters of fLVPS devices

Parameter	**Smoothing type**	**Time (sec)**	**Value**
ELMB current	Value and Time	18000	±0.2 mA
ELMB voltages	Value and Time	18000	±0.2 V
ELMB-MB current	Value and Time	18000	±0.2 mA
ELMB-MB voltages	Value and Time	18000	±0.2 V
Temperature	Value and Time	3600	$\pm 1^o C$

Table 11: Smoothing settings of the archived parameters of the AUX board devices

Parameter	**Smoothing type**	**Time (sec)**	**Value**
Channel Voltage	Value and Time	3600	± 0.5V
Channel Current	Value and Time	3600	± 5%
Channel Temperature	Value and Time	3600	± 1.0 ^{o}C

Table 12: Smoothing settings of the archived parameters of 200V PS devices

The frequencies of records for the parameters (voltages, currents and temperatures) of the fLVPS devices have been analyzed. The results are shown in Figure 6, which shows the frequencies of records into the Conditions DB during a one month period, for individual monitored parameters of the fLVPS devices. For stably working electronics, it is expected to have an average of one record during the time interval that is specific for the applied smoothing type (see smoothing definitions and Tables 10 - 12). Such a plot could be very useful to understand the detector behavior from the DCS point of view and easily visualize instabilities of the electronics.

During the one month period used, the read out of some of the monitored parameters stopped from time to time, usually due to communication problems, resulting in a few parameters showing values below one record per hour in Figure 6. Frequencies clearly above one per hour are caused by the big variation of monitored values of the output currents of a few modules/bricks, and will be investigated further.

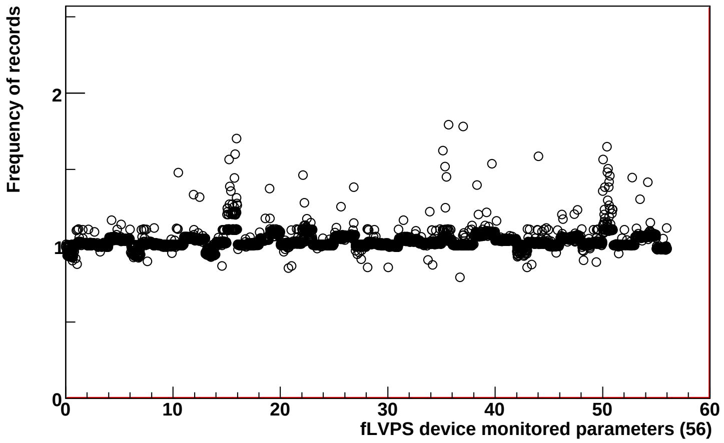

Figure 6: Frequencies of records (per hour) of the parameters of fLVPS device units.

7 Conclusions

This paper presents a comprehensive picture of the Tile Calorimeter DCS system, as implemented following the requirements of the ATLAS DCS integration guidelines. The DCS of the LVPS system has been ready on time and proved to be both user-friendly and robust. It was successfully operated in a reliable manner for almost 2 years. A key element in this successful implementation was the correct selection of the building blocks since the beginning of the implementation.

We present the organization of the supervisory level for the LVPS system, information necessary for the operator to have the ability of full control over the system, and a detailed description of the hardware components of the LVPS system with emphasis on the critical parameters of the system and their monitoring thresholds for ALARM and WARNING. Details of the commands implemented for the individual device units of the LVPS system are given as well as time estimates for their execution.

Usage of the Configuration and Conditions DB are also described in this paper. Analysis of the DCS data from the Conditions DB showed that the daily recorded data is reasonable in size and allows understanding of the LVPS system behavior. Implementation of the Configuration DB allows storing of the full information about the LVPS system calibration and nominal output voltages.

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A ELMB analog input settings

The configuration parameters for the analog inputs of the ELMB used in the finger LVPS are shown in table 13. All the 64 multiplexed inputs are read by the ADC, at a rate of 60 Hz. In practice the achievable rate of conversions is limited to about 30 Hz maximum due to the slow opto-couplers used in the (serial) interface between the processor and the ADC [13].

ELMB ADC properties	**Set**
Rate (Hz)	60
Range (V)	5.0
Highest channel number	64
Polarity	Bi-polar
Analog Input Transmission	After SYNC message only

Table 13: Configuration of the ELMB used in the LVPS system

B Address field configuration for AUX board initialization

The address field configuration for the start-up pulse set command is given in table 14. In the example, it is used to set the parameters of AUXboard12 (initialization of this AUXiliary board unit). The AUX board units need to be initialized before they are used to start-up the finger LVPS. Parameters like the duration of the start-up pulse are set in the initialization.

Parameter	**Set value**
Server	OPCCANopen
Group	Cmd_AUXboard
Item	AUXboard.AUXboard12.AUXINIT
Transition Type	Integer
Direction	Out

Table 14: Example of address field configuration for start-up pulse set command of one of the AUX boards.

C List of acronyms

ADC - Analog to Digital Converter
AUX (board) - Auxiliary board used to control fLVPS
BE - Back End
CAN - Controller Area Network
DAC - Digital to Analog Converter
DC-DC - Direct Current to Direct Current
DCS - Detector Control System
ELMB - Embedded Local Monitor Board
FE - Front End
fLVPS - finger Low Voltage Power Supply
FSM - Finite State Machine
GCS - Global Control Station
HV - High Voltage
JCOP - Joint COntrols Project (for LHC)
LCS - Local Control Station
LV - Low Voltage
LVPS - Low Voltage Power Supply
MB - Mother Board
OPC - a standard for communication of real time data, originally known as Object Linking and Embedding (OLE) for Process Control
PDO - Process Data Object
PMT - PhotoMultiplier Tube
PS - Power Supply
PVSS II - SCADA software used in ATLAS DCS
SCS - Sub-detector Control Station
SCADA - Supervisory Control And Data Acquisition
SDO - Service Data Object
TCP/IP - Transmission Control Protocol / Internet Protocol
TDAQ - Trigger and Data Acquisition
USA15 - Electronics cavern near the ATLAS detector