THE ATLAS TRANSITION RADIATION TRACKER (TRT) DETECTOR CONTROL SYSTEM

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Abstract

The TRT is one of the ATLAS experiment Inner Detector components providing precise tracking and electrons identification. It consists of ~350000 proportional counters (straws) which have to be filled with stable active gas mixture and high voltage biased. High voltage settings at distinct topological regions are periodically modified by closed-loop regulation mechanism to ensure a constant gaseous gain independent of drifts of atmospheric pressure, local detector temperatures and gas mixture composition. Low voltage system powers front-end electronics. Special algorithms provide fine tuning procedures for detector-wide discrimination threshold equalization to guarantee uniform noise figure for whole detector. Detector, cooling system and electronics temperatures are continuously monitored by ~ 3000 temperature sensors. The standard industrial and custom developed server applications and protocols are used for devices integration into unique system. All parameters originating in TRT devices and external infrastructure systems (important for Detector operation or safety) are monitored and used by alert and interlock mechanisms. System runs on 11 computers as PVSS (industrial SCADA) projects and is fully integrated with ATLAS DCS.

INTRODUCTION

TRT Detector

The TRT (Transition Radiation Tracker) is a part of the Inner Detector [1] tracking system of ATLAS experiment built at CERN for the Large Hadron Collider (LHC). It covers |η|<2.5 in pseudo rapidity at radii between 128 and 206 cm, allows for electron-pion separation at 97% level and provides continuous tracking with accuracy ~120 μm/point. The detector has three parts – barrel and two end-caps – which consist of arrays of the thin walled proportional counters – straw tubes. The barrel detector contains 96 parts called modules (3 layers of 32 modules). The end-caps consist of 14 'wheels' each, where wheel is functionally divided into 32 sectors. Each module and sector has its own individual electrical services (HV, LV, timing etc). The straw configuration gives ~36 space measurement points in whole TRT acceptance. The detecting elements act as drift tubes ensuring the tracking function and measure energy deposit in specially chosen

active gas allowing for efficient detection of the transition radiation photons thus performing identification function.

ATLAS Detector Control System (DCS)

The ATLAS DCS is a large distributed hierarchical control system integrating all subdetectors and infrastructure systems. PVSSII from ETM [2] is a commercial product chosen as a standard SCADA for CERN control systems. The CERN Joint Controls Project (JCOP) Framework [3] provides guidelines and components for integration of commonly used hardware and services into a homogenous control system. ATLAS Central DCS group provides ATLAS-specific guidelines and framework components. The Finite State Machine (FSM) [4] component is used to build and integrate ATLAS DCS hierarchy providing scalability and powerful tools for partitioning of large systems. The main FSM building blocks modelling behaviour of hardware objects are Device Units (DU) and groups of devices are Control Units (CU). States and statuses propagate up in the FSM hierarchy, while commands propagate down the tree. For each FSM node in a hierarchy, two GUI operator panels (primary and secondary) have to be developed. Operator panels can be extended by expert oriented elements controlled by Access Control. The effort needed for design and construction of the control system for LHC experiments in many cases surpasses the possibilities and available manpower of groups involved. This has resulted in wide use of commercial equipment and software tools making the tasks possible to achieve. OPC (OLE for Process Control) standard has been adopted by CERN as one of the mandatory specifications for commercial equipment purchased for LHC experiments.

THE TRT DCS

The TRT DCS subsystems controlling hardware directly connected to the detector are organized to follow Data Acquisition architecture – End Cap A , End Cap C, Barrel A and Barrel C FSM nodes. Each of them contains High Voltage, Low Voltage and Temperature nodes. All other FSM sub-trees are grouped under an Infrastructure node. Four PCs control LV Distribution and Temperatures Monitoring Systems, three PCs control HV

Distribution System, one PC is assigned to infrastructure and whole hierarchy is supervised by top located PC.

High Voltage Distribution System

The TRT High Voltage is based on HVSys company Multichannel Crates with SC508 controllers [7]. The SC508 controller provides communication through RS-232 interface with custom designed protocol. There is no parameters' polling loop embedded in HVsys crate firmware. A boot up message is the only one which the crate sends out autonomously. Six HVSys crates are located in ATLAS underground counting room, 1984 individual lines of length ~70 m distributes HV for both End Caps and Barrel. Three PVSS projects control ~14000 set-point registers and monitor ~18000 measured values and statuses.

A custom OPC DA server was developed (using Softing OPC Toolbox) as an integration middleware for TRT HV PVSS projects. SC508_OPC supports calibration files for Digital-to-Analogue Converter (DAC) and Analogue-to-Digital Converter (ADC) of each HV Cell. One of the main difficulties during commissioning was tuning of performance of HV PVSS systems. The 2-port PCI/RS232 interface cards showed to be more efficient communication solution than USB HVSys crates interfacing. The separate OPC server threads are handling each of serial ports. Separate "fast transaction" queues support commands and status information handling. Each OPC server handles 9 OPC groups defined in order to spread in time PVSS Event Manager load during periods of full TRT Detector transition between HV operational states.

The FSM for HV systems adopts majority logics for states decoding. It allows a small fraction of cells to be tripped or recovering without data taking disturbances.

Two guarding mechanisms were added when an operational experience has been cumulated:

- There are values stored locally in HV cells which do not need to be changed during states transitions. They define cell's behaviour during over-current hardware trip procedure. Trip registers values are refreshed to prevent their corruption - one cell every 3 min.
- A watchdog covering a full communication path for each of HV crate was developed. One HV spare cell per crate is used for it. Each 3 minutes a new HV set-point value is sent to a Watchdog Cell. The read back from set-point register and the output voltage value are compared with a previous watchdog setting. HV watchdog is a very sensitive tool for detecting cases when system suffers from PVSS OPC Client memory leaks, internal HV crate communication problems, OPC server operation slow down or other HV communication degradation.

Low Voltage Distribution System

The Low Voltage TRT system has been detailed elsewhere [8]. The TRT performance and good quality data readout depend on proper level of supply voltages,

assuring the correct operation of the Front End (FE) electronics during life cycle of the experiment.

The data/control flow in the LV FE part during standard detector operation is the following:

- Output voltages, currents and intermediate board's (LVPP - located within ATLAS detector) temperatures are continuously monitored in the PVSS projects. These data are read out over CANbus via CanOpen OPC server from the ELMB [5] embedded on the board.
- Settings of DACs (defining output voltage level) are read back from the LVPP employing TRT custom Dynamic Link Library (DLL), embedded as an extension to PVSS CTRL scripting language. This readout is performed after every change of DAC values, before switching on voltages, and on demand.
- OCM (Over Current Monitor) values are read back from the LVPP with mentioned TRT custom DLL every 20 minutes.
- Values of supply voltages and temperature directly at the FE: Voltage/Temperature (VT) are read by the Data Acquisition (DAQ) system and are sent to the DCS via the DCS-DAQ Communication (DDC) mechanism. This readout is done at every run start and on demand.
- All operations (switching on/off, writing new DAC setting to the hardware, etc.) in the LV FE system are executed by FSM commands, available from PVSS FSM GUI. These commands are transmitted via CANbus employing already mentioned TRT custom DLL.

Temperatures Monitoring

The TRT detector operates in ambient temperature. It should be kept in proper temperature ranges because of detector and electronics safety and mechanical structure stability. The detector is exposed to heating coming mainly from FE electronics. It can also suffer from cooling which comes from the silicon detectors placed inside the TRT, when the insulating envelope heaters fail.

Two types of temperature sensors are installed in the TRT detector:

- NTC, mounted directly on the FE electronic boards.
- PT1000, mounted on different structures in the detector.

The following are groups of sensors installed on different parts of the detector:

- 1720 NTC's on FE boards - acting an important role in LV interlock
- 496 PT1000's on FE boards cooling pipes
- 160 PT1000's on mechanical structure of the detector
- 288 PT1000's between detector modules in Barrel and in straw's cooling CO_2 flow – acting as sensors for mean temperature calculations for GGSS to HV feedback.

- 48 PT1000's on heat exchangers cooling pipes in End Caps
- 32 PT1000's on input pipes of straws' cooling CO_2 flow in Barrel

Sensors' values are monitored by ELMB embedded on the TTC PP boards. Calibration constants were measured for each cable with a PT1000 sensor and are used in CanOpen OPC server configuration files.

Alarm limits are set individually for each sensor. They trigger emergency and notification actions and are used in temperature FSM nodes.

TRT Infrastructure Subsystems

There are following auxiliary subsystems fully integrated with TRT DCS, but not connected directly with a detector:

- Maraton Bulk Power Supplies which deliver primary LV for LVPP distribution boards (and other Patch Panel boards) and DAQ VME Crates are commercial devices delivered by WIENER company. A common OPCserver handles both types of devices, merging Maratons' Ethernet communication with CANbus one for VME crates. Framework components are supported by CERN EN/ICE group.
- The Hardware Interlock box for LV system is supervised by built-in ELMB's, thus it can be monitored using a standard middleware layer.
- CANbuses Power Supply Units deliver voltages for 25 CANbuses used in the TRT. Standard tools delivered by ATLAS DCS group were used for integration to TRT DCS. The above Infrastructure nodes are controlled from one PVSS system.
- To achieve the necessary performance of the TRT, the gas gain should be kept constant. It depends on actual active gas composition, concentration of impurities, ambient pressure, local detector temperature and high voltage bias which can be used as a parameter compensating drifts of other values. The dedicated standalone Gas Gain Stabilisation System (GGSS) was developed. The standalone process running in closed loop collects Fe^{55} spectra from reference straws with TRT active gas flowing through and corrects HV biasing sensors as to keep spectra peak positions at required level after every iteration. GGSS is a source of reference HV value and reference temperature which are used by TRT High Voltage Systems for periodical corrections of HV cell's output voltages. A detailed description of hardware architecture and a stabilisation algorithm can be found in [9]. A dedicated Distributed Information Management (DIM) server [6] integrated with the stabilization process is used to send stabilization results and status messages to PVSS system and receive commands from FSM. The normalized HV reference value calculation was added as a result of operational experience. It is a difference between measured reference HV and a predicted value calculated on base of atmospheric pressure and local temperature measured values.

Normalized HV reference is a very sensitive parameter guarding active gas composition.

- The Active Gas Chromatograph is a commercial standalone system running on one PC and integrated with TRT DCS by periodically fetching analysis results from an output file.

ATLAS Infrastructure Subsystems

The TRT detector uses centrally delivered and maintained infrastructure hardware and services. It's very important to monitor parameters which directly can influence the detector operation. One can copy or subscribe needed data from Information Services Systems or PLC's which control external systems. The following external systems parameters sets are integrated within TRT DCS Infrastructure node:

- Active Gas System – delivers a gas mixture (70% Xe, 27% CO_2, and 3% O_2) circulating in closed loop system.
- Straws Cooling – removes heat dissipated in straws by ionisation. It circulates (CO_2) between straws.
- FE electronics & Cables Cooling – liquid (C_4F_{16}) circulation.
- Detector Safety System – displays triggers & action bits from hardware matrix.
- Common Infrastructure Control – controls racks and environmental sensors.
- PVSS Systems Overview – monitors and controls SCADA managers and OPC servers states in all DCS computers.

TRT DCS OPERATIONAL AUTOMATION

Software Safety Interlocks

There are two software interlock mechanisms implemented in the TRT DCS system. The LV interlock monitors temperatures measured on FE electronics boards. It switches off the FE LV in case of overheating. The HV interlock is triggered when Active Gas composition or its flow became not safe for straws (danger of discharges) or when humidity in racks housing HV power supplies became too high (danger for HV power supplies). It sequentially sets action flags (SAFE_HV, PREPARED, OFF) after programmable delays. All HV cells DU's call back functions perform required actions and block operator actions to set higher voltages until flags are active.

GGSS to HV Feedback

The GGSS provides reference HV and reference temperature for actual active gas mixture. Selected groups of temperature sensors are used to calculate mean temperature in different detector regions. Each 3 min. a timer triggers execution of a script which checks if GGSS references can be trusted and loops over all connected to detector HV cells performing the following steps:

- Checks if corresponding region temperature can be trusted.

- Calculates a new HV cell's set-point (basing on HV reference and temperatures difference between region and GGSS straws box).
- Checks if a new set-point value doesn't exceed acceptable range.
- Sends a new set-point value to HV cell, if all safety checks succeeded. If any of them fails, the GGSS to HV feedback is disabled till expert checks a situation and re-enables it.

The GGSS feedback corrects HV set-points for cells which are switched to state ON by FSM commands only, thus not interfering with manual operator or expert actions.

Cell Automatic Trip Recovery

The HV cells trips are usual events during the TRT detector operation and have to be carefully handled by experts who decide:

- which of the often tripping cells can be automatically switched back on,
- how many times the cell can be recovered (per day and since last counter reset),
- how long the automatic action has to be delayed.

After a delay HV cell's DU call back function automatically sends a sequence of commands to set a nominal voltage. Automatic trip recovery is performed when the trip happened from cell's ON state only.

LV Settings Equalisation

The distances between LVPP's and the detector FE boards range from 11 to 14 m. Also the current consumption of FE boards differs according to their function within the detector. There are in total 1792 FE boards in the system, each supplied with 3 voltages. Voltages levels at FE should be equal to nominal, so each voltage in the LVPP should be set to a unique value. Setting voltages levels is done via DACs (Digital-to-Analogue Converters) in the LVPP's. The setting is done after each longer shutdown period, board replacement or at any time, when there are some doubts on proper detector performance.

The Low Voltage Equalization Procedure has been prepared for this purpose. Its usage is foreseen not only for setting DAC values but also for debugging and checking the entire LV system in case of problems with operation of FE electronics. The Low Voltage Equalization Procedure consists of an external DAQ LV Equalization application calculating DAC values and mechanisms in PVSS project, including Framework components, which set these values to the hardware.

The DAQ LV Equalization application is performing calculations of DAC settings, and alarm limits for voltages and currents for each voltage type in individual FE board. Primary calculations are based on direct VT readout from the FE. The following, second way of calculations is for comparison and checks. Input parameters for this method are voltages and currents in the LVPP's and previous DAC settings, which are stored in the PVSS archive. These calculations are based on hardware topology, cables resistance and connection of grounds. Calculation results predict values of DAC settings and limits of alarms. They are stored in recipes in the Configuration DB and applied to the hardware from the PVSS project.

A PL/SQL API interface - consisting of a set of routines stored in the Oracle database server, being a part of the Configuration DB schema and allowing access to database data has been developed. These routines, called API Stored Procedures, are used by the DAQ LV Equalization application for fetching necessary data from the PVSS archive and storing output data to recipes in Configuration DB.

CONCLUSIONS

The TRT DCS is operating the detector very stably and reliably and is an important factor for detector safety, excellent performance and good quality of data taken during LHC collisions.

The hardware failures can't be avoided in such a big and complex system. Some of them can be recovered without stopping the ATLAS data taking, especially during LHC collisions, but a dedicated DCS tools for it need to be developed. HV cables „hot swap" to a spare (free) connector position tool is already in operation, the other will come in a near future.

ACKNOWLEDGEMENTS

REFERENCES

[1] Inner Detector Technical Design Report ATLAS TDR 4, CERN/LHCC/97-16 (1997).

[2] ETM professional control: PVSS, http://www.etm.at

[3] O. Holme et al. "The JCOP framework", ICALEPCS 2005, Geneva.

[4] C. Gaspar and B. Franek, Tools for the automation of large distributed control systems, IEEE Trans. Nucl. Sci. 53 (2006) 974.

[5] B. Hallgren et al. "The Embedded Local Monitor Board (ELMB) in the LHC front-end I/O control system", in Proc. 7th Workshop on Electronics for the LHC Experiments, Stockholm, Sweden, 2000.

[6] Gaspar, C., et al., Comput. Phys. Commun., vol 140, pp. 102-109, 2001.

[7] http://www.hvsys.dubna.ru/SC508_atl.pdf
http://www.hvsys.dubna.ru/CELL_ATL.pdf

[8] Z.Hajduk et al. "Distributed Low Voltage Power Supply System for Front End Electronics of the TRT Detector in ATLAS Experiment", in Proc. of the 12th Workshop on Electronics and Future Experiments, València, Spain, 2006.

[9] M. Deptuch et al. Gas Gain Stabilisation System prototype for the TRT - ATL-INDET-2002-010.

[10] Z.Hajduk et al. Gas Gain Stabilisation System - from model and prototype to final construction ATL-IT-ER-0025.