CONTROL SYSTEM FOR PRE-PRODUCTION TESTING OF THE ATLAS ITk PP2*

Maria Dudek

Institute of Nuclear Physics Polish Academy of Science
Radzikowskiego 152, 31-342 Kraków, Poland

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ATLAS (A Toroidal LHC Apparatus) detector will undergo modernization between 2026 and 2030 to prepare for operations in the high-luminosity regime of the High-Luminosity Large Hadron Collider. Patch Panel 2 (PP2) is an active component of the strip tracker's power supply (PS) chain, which will be located inside the ATLAS detector. For safety and control reasons, an independent readout system is needed to connect to PP2. This paper presents the PP2 control and monitoring system as implemented during the prototype and pre-production phases and outlines the quality control plans for the pre-production PP2 series currently under development in Kraków.

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1. Introduction

The High-Luminosity Large Hadron Collider (HL-LHC) [1] project aims at increasing the integrated luminosity by a factor of 10 compared to the LHC's design value to enable more accurate measurements of the Standard Model, study the properties of the Higgs boson, and search for physics beyond the Standard Model. However, such a large increase in luminosity means that experiments at the LHC [2] must cope with increased radiation levels in the detector volume, higher data rates, and an extremely high-occupancy environment. The ATLAS detector [3] is undergoing modernization to prepare for operation in a high-luminosity regime. In particular, the existing inner detector will be replaced with a new system known as the Inner Tracker (ITk) [4].

The ITk will be a new all-silicon pixel and strip tracker with a highly optimized layout to minimize the amount of material while maximizing the number of hits per charged particle track. The outer part of the ITk is the

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Strip Detector [5]. It contains six end-cap disks built of petals and four barrel layouts made of staves. Short- and long-strip modules are building, respectively, two inner and two outer barrel layouts.

2. The power supply system of ITk strips detector

The strip detector needs two types of power supplies: low voltage (LV) for the readout electronics on the module and high voltage (HV) to bias the silicon sensor. The ITk strips power supply (PS) crates located at the service caverns outside the detector provide both (LV = 48 V, HV = −550 V). The cables leading to the detector are more than 100 meters long. To improve efficiency and reduce ohmic power loss, a two-step DC/DC conversion system is used: an intermediate step-down DC/DC converter (48 V to 11 V) is located on Patch Panel 2 (PP2) [6], followed by a final step-down DC/DC converter (11 V to 1.5 V or 2.5 V) on the end of substructure board.

3. Patch Panel 2

PP2 is a custom design, modular, radiation, and magnetic field tolerant DC/DC converter that is being developed in Krakow by AGH University of Krakow and Institute of Nuclear Physics Polish Academy of Sciences [6]. After modernization, PP2 will be located inside the ATLAS detector in ten positions between muon chambers and the calorimeter.

PP2 consists of custom crates with embedded cooling plates, crate controller, and insertable DC/DC boards containing two or four output channels (high and low power cards). Each DC/DC channel comprises a 48-to-11 V DC/DC converter, hardware overcurrent protection, an overvoltage circuit, correction circuitry to compensate for voltage drops along the cables, and control and monitoring functionality based on the AMACStar chip [7].

There are two types of PP2 crates: one containing high power cards designed to serve barrel short-strip staves and one containing low power cards for barrel long-strip staves and end-cap petals. The main differences between the two types of boards are the maximum output power and the distribution of the HV lines.

4. Monitoring and control system for PP2 pre-production tests

The Detector Control System (DCS) [5] is needed to ensure the coherent operation of the PP2 equipment and to provide a homogenous interface to all subcomponents and the other parts of the ITk detector. At the stage of the PP2 pre-production, the DCS is crucial for implementing the functionality and procedures needed for safe operations, tests, and data quality procedures.

4.1. PP2 Hardware readout chain

The hardware part of the PP2 DCS readout chain is based on the custom solutions developed for the HL-LHC experiments. The PP2 crate controller contains an Embedded Monitoring and Control Interface (EMCI) [8] that communicates with AMACStar chips on the PP2 cards by means of e-links distributed in the crate backplane. The EMCI board was selected to be used as a PP2 controller as it is radiation and magnetic-field tolerant and conforms to the environmental requirements in the ATLAS cavern. Every EMCI contains one lpGBT (Low Power GigaBit Transceiver) chip [9]. The lpGBT is a highly flexible link interface chip that can be configured to be a bidirectional transceiver.

The EMP [10] is a custom-designed readout board that provides both Central Processing Unit (CPU) and Field-Programmable Gate Array (FPGA) logic. The CPU runs Linux and operates like a normal PC, while the FPGA part drives lpGBT optical links. Optical links connect one EMP to up to 12 EMCI boards.

A schematic view of the pre-production version of the PP2 readout and monitoring chain is shown in figure 1.

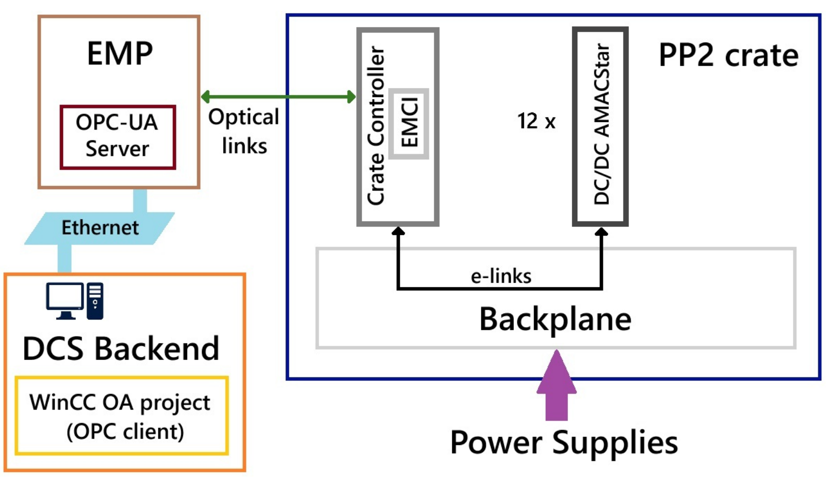

Fig. 1. Diagram of the PP2 DCS system: The Crate Controller board, located in the first slot of the PP2 crate, connects via optical links to the back end of the Detector Control. The Crate Controller is based on the EMPI board and communicates via e-links on the crate backplane with the DC/DC channels. Control and monitoring of the DC/DC channels are handled by the AMACstar chip. The Crate Controller also communicates with the Embedded Monitoring and Control Processor (EMP) readout board, which then transmits the data to the Detector Control System program.

4.2. Software readout chain

The industrial WinCC OA [11] supervisory control software toolkit was chosen to build the DCS application. The choice of WinCC OA is significant due to its scalability and flexibility, which allow for customization and integration with various subsystems. WinCC OA offers features like real-time monitoring and control, alarm management, data visualization, and scalability to handle large systems and complex setups, starting from PP2 test bench up to the whole ITk detector.

EMP runs the OPC-UA server [12] application, which allows for the integration of monitoring data into the backend of PP2 DCS. The PP2 DCS application is built within the WinCC OA framework, which provides an OPC-UA client interface.

4.3. PP2 DCS for the prototype and pre-production test bench

Multiple activities are involved in developing a new system like ITk, and the dependencies between tasks can create challenges in aligning the final delivery. For example, the final EMP boards were unavailable during the PP2 prototyping and pre-production testing, so an alternative solution built around a Trenz System-on-Module [13] was implemented. The integration of the Trenz System-on-Module as a temporary solution during the PP2 pre-production testing addresses the absence of the EMP boards while still providing critical functionality for testing and validation.

After the prototype-EMP board was successfully connected to the PP2 system, tests are being conducted on our WinCC OA DCS project that should serve as the user interface of the PP2 control system. The PP2 DCS project used in the ITk trip system tests has been modified to serve the needs of the PP2 pre-production testing and data quality checks.

The project currently monitors critical parameters such as current, voltage, and temperature that are being measured by the AMACstar chips on the DC/DC cards in the PP2 system. Monitoring these values ensures that the equipment is operating within safe parameters and that any anomalies are quickly detected.

The measurements are being saved to an Influx database [14], which is an excellent choice for time-series data, providing high performance and flexibility for querying over time. This makes storing and analyzing large volumes of collected data easier for diagnostics, long-term analysis, and trends.

4.4. Quality control aspects implemented in PP2 pre-production DCS

Quality control (QC) is a set of procedures designed to ensure that a manufactured PP2 system complies with a defined set of quality criteria. In the case of PP2, it must be considered that there is only limited access to PP2 equipment during experiment data taking. This forces a more rigorous QC that checks whether PP2 meets specific standards: conforms to electrical, mechanical, and thermal specifications; is radiation tolerant and magnetic-field tolerant.

The QC procedures will be implemented during the PP2 pre-production and production using DCS tools and strategies. Measurements and procedures will be automated when possible, and data will be archived and used for analyses with interpretation. Including data quality procedures in the DCS implies a focus on monitoring the quality and integrity of the data collected from the PP2 and implementing the procedure for automated diagnostics and self-testing. The automated diagnostic checks can run on a scheduled basis to test the health of the DC/DC cards and other equipment. These check for common faults or provide alerts if any equipment is not performing as expected. Self-testing routines are integrated to verify the readings from the AMACstar chips and DC/DC cards against expected values and to verify communication at each stage of the readout system.

5. Summary

The ITk Strip power supply system is built with equipment such as Patch Panel 2, a radiation and magnetic-field tolerant modular system that distributes power to the detector. PP2 features custom crates, embedded cooling, and various safety mechanisms such as overcurrent protection and voltage correction. The Detector Control System is a key to ensuring PP2's safe and efficient operation at the pre-production testing stage. It provides monitoring, control, and data quality checks.

For the pre-production tests being developed in Kraków, a temporary solution using the Trenz System-on-Module was employed due to the unavailability of the final EMP boards. The WinCC OA software is used for supervisory control, providing real-time monitoring and integration with the DCS.

The quality control procedures are crucial to ensure the PP2 system meets specifications and tolerances. Integrated into the DCS, these procedures include automated diagnostics, self-testing, and routine checks to ensure equipment performance. The pre-production QC focuses on a large sample, while production QC targets representative samples, with statistical analysis guiding further improvements.

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REFERENCES

[1] CERN, «High-Luminosity LHC», https://www.home.cern/science/accelerators/high-luminosity-lhc

[2] P. Jenni, T.S. Virdee, «The Discovery of the Higgs Boson at the LHC», in: H. Schopper (Ed.) «Particle Physics Reference Library», Vol. 1: Theory and Experiments, *Springer Open*, 2020, pp. 263–309.

[3] ATLAS Collaboration (G. Aad *et al.*), *J. Instrum.* **3**, S08003 (2008). Also published by CERN Geneva in 2010.

[4] ATLAS ITk Collaboration (L. Gonella), *Nucl. Instrum. Methods Phys. Res. A* **1045**, 167597 (2023).

[5] S. McMahon *et al.*, «Technical Design Report for the ATLAS Inner Tracker Strip Detector», CERN-LHCC-2017-005; ATLAS-TDR-025, 2017.

[6] M. Dyndał *et al.*, *J. Instrum.* **18**, C01007 (2023).

[7] T.C. Gosart *et al.*, *J. Instrum.* **18**, C02013 (2023).

[8] D. Blasco Serrano *et al.*, *J. Instrum.* **17**, C06012 (2022).

[9] P. Moreira *et al.*, *IEEE Trans. Nucl. Sci.* **72**, 24 (2025).

[10] P. Moschovakos *et al.*, in: «Proceedings of the 19^{th} International Conference on Accelerator and Large Experimental Physics Control Systems, Cape Town, South Africa», *JACoW Publishing*, Geneva, Switzerland, 2023, pp. 1470–1474.

[11] Winccoa, «WinCC OA Documentation», https://www.winccoa.com/documentation/WinCCOA/latest/en_US/index.html

[12] OPC Foundation, «OPC UA Online Reference — Released Specifications», https://reference.opcfoundation.org/

[13] Trenz Electronic, «MPSoC Module with AMD Zynq™ UltraScale+™ ZU4EG-1E incl. Heat Spreader», https://shop.trenz-electronic.de/en/TE0807-04-4BE81-AK-MPSoC-Module-with-AMD-Zynq-UltraScale-ZU4EG-1E-incl.-Heat-Spreader

[14] influxdata, «InfluxDB OSS v2», https://docs.influxdata.com/influxdb/v2/