

Test and Evaluation Station (TESt)

A control system for the ALICE-HMPID liquid distribution Prototype

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Abstract

The sub-detectors and systems in the ALICE experiment[1] are of various types. However, during physics runs, all devices necessary for the operation of the detector must be accessible and controllable through a common computer interface. Throughout all other periods each sub-detector requires maintenance, upgrading or test operation. To this end, an access independent of other sub-detectors must be guaranteed. These basic requirements impose a fair number of constraints on the architecture and components of the Detector Control System (DCS)[2].

The purpose of the TESt project consisted in the construction of a stand alone unit for a specific sub-system of an ALICE detector in order to gain first experience with commercial products for detector control. Although the control system includes only a small number of devices and is designed for a particular application, it covers nevertheless all layers of a complete system and can be extended or used in different applications.

The control system prototype has been implemented for the Perfluorohexane (C₆F₁₄) liquid distribution of the ALICE-HMPID (High-Momentum Particle Identification)[5]. The application has been developed exclusively with components off the shelf: National Instruments BridgeVIEW[6] supervision software, SIEMENS PLC S7-300[7] and the programming tool STEP 7. The OPC standard (OLE for Process Control)[8] was used for the communication between BridgeVIEW and the PLC.

Control system, SCADA, STEP 7, BridgeVIEW, PLC, OPC.

1 Introduction

The JCOP (Joint COntrol Project)[4] was set up at the beginning of 1998 to look for common solutions for the detector control of the future LHC experiments. The common project teams have already started a number of work items. However, until a complete proposal can be submitted, it will be necessary to implement already now some control equipment for R&D and test beam runs. In order to maintain the largest portion of this investment an interim development toolkit has been proposed. The homogenous development environment shall allow at a later stage a smooth migration to the final supervisory system.

The TEST (Test and Evaluation Station) project was setup in ALICE, it includes the hardware and software configuration of a basic control assembly ready to control the operation of the liquid distribution for the ALICE-HMPID prototype with off the shelf components complying with the currently proposed standards (Fieldbuses[9], PLC[10])

The ALICE HMPID (High-Momentum Particle IDentification) detector is a RICH (Ring Imaging CHerenkov) detector. A prototype has been developed by the EP-TA1 group. The IT-CO group has been requested within the framework of JCOP to participate in the development of the control system of the liquid distribution prototype. Although this application is provisionally limited to the detector prototype, the experience gained is valuable for the control of the LHC experiments. It allows the acquisition of knowledge in industrial technologies such as PLCs, programming tools and OPC for data exchange with the supervisory software.

2 HMPID liquid distribution prototype

The liquid distribution of the prototype (Figure 1) is a simplified version of the system required for the final HMPID detector.

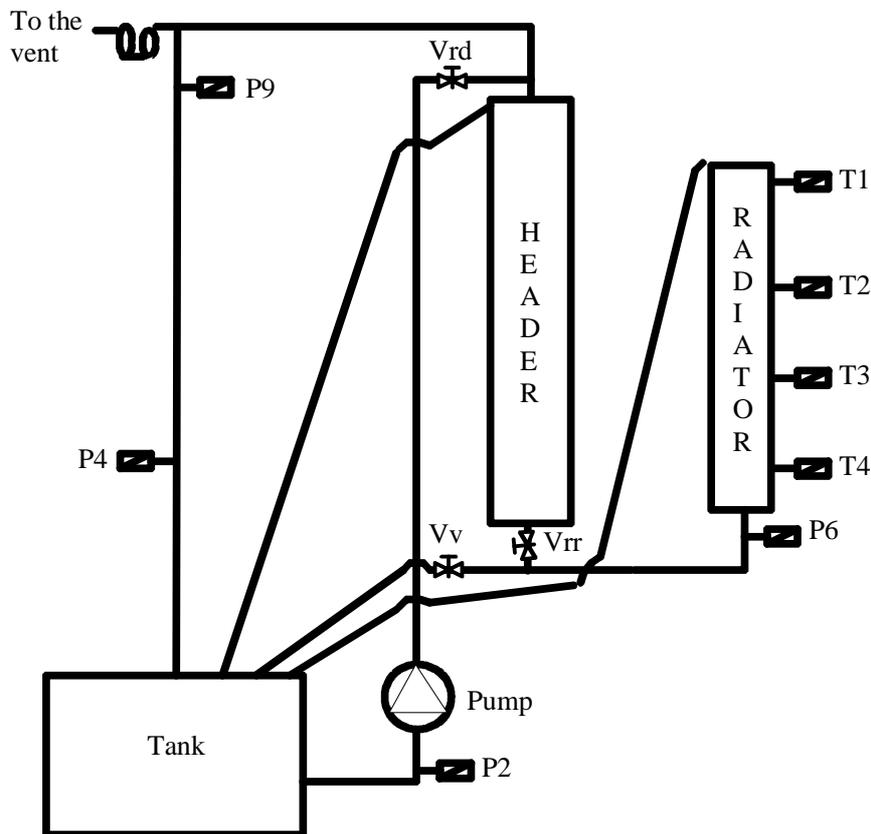


Figure 1: The HMPID C6F14 liquid distribution prototype.

The liquid flow through the radiator circuits is controlled by electro-pneumatic valves. Pressure gauges and temperature sensors, located at different points are used for

monitoring. The installed sensors and actuators work with standard current and voltage ranges: electrical valve (0-24 V), pressure gauge (0-10 V/4-20 mA), temperature probes (pt100, 0-500 mV), pump (220 V). The electrical valves and the pump can be operated locally by buttons or by remote computer control. Local or remote operation can be selected with a set of switches which act as password selectors. The installation consists of 8 analog inputs, 4 digital inputs, 7 digital outputs. In addition 16 digital inputs are used for password selection from a PLC input module.

2.1 Control Strategy

The liquid is pumped from the tank to the header tube when the electrical valve Vrd is opened. The radiator is filled from the bottom inlet when the electrical valve Vrr is opened. Excess liquid returns from the header tube and radiator through the overflow line to the tank. The radiator can be purged when the electrical valve Vv is opened. To purge the header both electrical valves Vrr and Vv need to be open.

At a set pressure, the pump can be stopped, and the valves upstream of the header and the radiator can be closed. When the filling of the radiator is started by opening the Vrr valve, the purge valve (Vv) can be automatically opened during a few seconds to prevent an over-pressure. This auto-purge condition can be selected by the operator.

Table 1 describes the states for the C6F14 liquid distribution. Every pressure measurement Px has a minimum and maximum value, respectively minPx and maxPx.

Table 1: HMPID C6F14 liquid distribution conditions.

Condition	action
P2 and P9 are outside limits (respectively minP2, maxP2 and minP9, maxP9)	pump stopped
P2 and P9 are inside limits (respectively minP2, maxP2 and minP9, maxP9)	pump ready to start
pump has been started, P2 and P9 are outside limits (respectively minP2, maxP2 and minP9, maxP9)	pump stopped
pump has been started, P2 and P9 are inside limits (respectively minP2, maxP2 and minP9, maxP9), P4 is still outside limits (respectively minP4 and maxP4) a few seconds (user programmable time-out) after the start of the pump.	pump stopped
pump stopped	header valve Vrd is closed
pump started	header valve Vrd can be opened
header valve Vrd is opened and P6 is inside limits (respectively minP6 and maxP6)	radiator valve Vrr can be opened

Table 1: HMPID C6F14 liquid distribution conditions.

Condition	action
radiator valve Vrr is opened and P6 is outside limits (respectively minP6 and maxP6)	radiator valve Vrr closed
radiator valve Vrr is requested to be opened and the operator selected an automatic purge of the radiator	radiator valve Vrr opened, purge valve Vv is opened during a few seconds (user programmable time-out) and then closed
valve Vrr is set to be closed before the end of the automatic purge and the automatic purge mode has been set	radiator valve Vrr and purge valve Vv are closed
header valve Vrd and radiator valve Vrr are opened, purge valve Vv is closed, P6 is inside limits (respectively minP6 and maxP6) and P6 is greater than the requested value for physics run	HMPID system is in state "ready for physics"

2.2 System architecture

The software architecture for the HMPID prototype includes two distinct layers:

- the process control level at which the actuator and sensor hardware are accessed and the automatic control (closed loop control system) for the liquid distribution is performed
- the supervisory level including Human Machine Interface (HMI), logging, archiving, security and trending.

Both layers can be operated completely independent from each other.

The purpose of the TEST project was to look at off the shelf components to implement this process and supervisory control. The following technologies were used in the HMPID liquid distribution prototype (refer to the document "First experience with PLC, OPC and BridgeVIEW in the context of the HMPID liquid distribution prototype"[3] for more information on the tools and technologies used):

- BridgeVIEW for the supervisory layer
- SIEMENS PLC for process control layer
- OPC as a standard device interface.

2.2.1 Process control

The process control is implemented in a PLC S7-300 from SIEMENS and SIEMENS analog and digital input/output modules. Modules and CPU are connected through a SIEMENS proprietary bus.

A PLC includes a power supply, a CPU and input/output modules mounted in a rack. Modules and CPU are connected through a SIEMENS proprietary bus (Figure 2) or geographically distributed by using a fieldbus such as PROFIBUS[11].

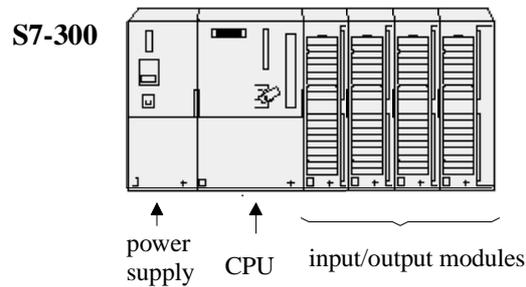


Figure 2: PLC with local input/output module.

The control program for the PLC is set up in a special development environment and then downloaded to the CPU. A user program is composed of the following items (Figure 3):

- **OB: Organization Block.** OBs are called by the operating system. Three kinds of OBs exist: OBs executed at the start-up of the CPU; OBs executed under defined conditions or at periodic intervals, OBs executed on interrupts or errors detected by the CPU. The available OBs are a function of the CPU type. Each OB has a priority and is executed in descending order of priority.
- **SFC: System Function.** This is a function like a system call in the C programming language.
- **FC: User Function.** It consists of a user supplied function with inputs and outputs but without memory block.
- **FB: Function Block.** This is similar to a FC with a block of memory (DI) associated to it.
- **SFB: System Function Block.**
- **DB: Data Block.** This is a memory area containing data of the user program. DBs can be opened and closed dynamically.
- **DI: Instance Data Block.** This is a DB associated with a FB. One FB can have multiple DIs.

Different memory areas are reserved for the storage of parameters and variables:

- **I memory:** process image of the inputs
- **M memory:** bit memory
- **Q memory:** process image of the outputs.

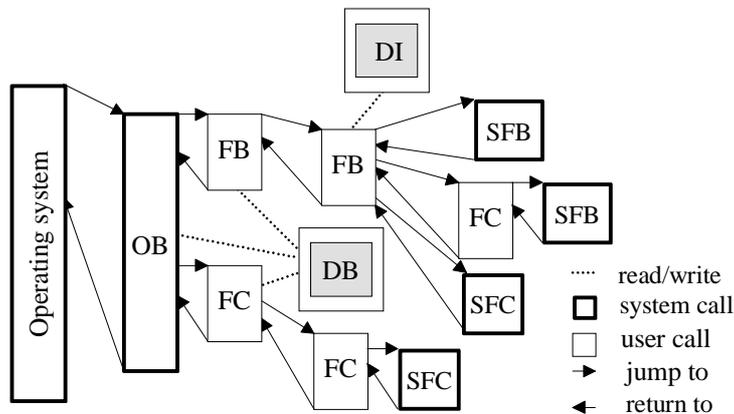


Figure 3: User program module organization.

The SIEMENS PLC operates in polling mode with defined execution cycles. Figure 4 illustrates the phases of the cyclic program execution:

- the operating system starts the cycle monitoring time.
- the operating system copies the value of the digital input module mounted in the CPU rack to the I memory area of the CPU.
- the operating system processes the user program (OBs) and executes the instructions in the user program. The user program has to read/write the analog values of the analog module mounted in the CPU rack and the values of the digital or analog modules distributed via a fieldbus to/from DB or M memory area. The user program has read and write access to the I and Q memory area.
- the operating system writes the values from the Q memory area to the digital output modules mounted on the CPU rack.
- at the end of the cycle, the operating system executes any tasks that are pending, for example loading and deleting blocks, receiving or sending data to remote PLC, etc.
- the operating system returns to the start of the cycle and restarts the cycle monitoring task.

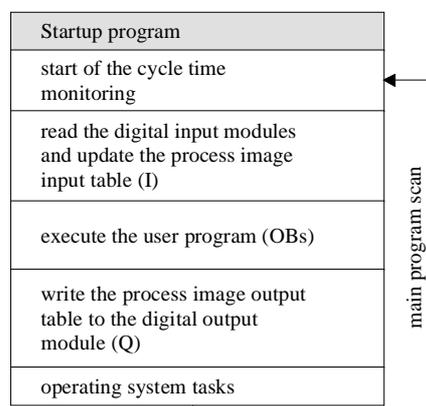


Figure 4: PLC program scan

The development software STEP 7 for configuring and programming the S7 PLCs includes tools for:

- setting up and managing a project
- configuring and assigning parameters to hardware
- configuring communication links
- creating the programs for the PLC using the standard IEC 1131-3 (International Electrotechnical Commission's standard) languages like FBD (Functional Block Diagram) (Figure 5), LAD (LADder logic) or STL (Satement List)
- downloading and testing the programs in the target system.

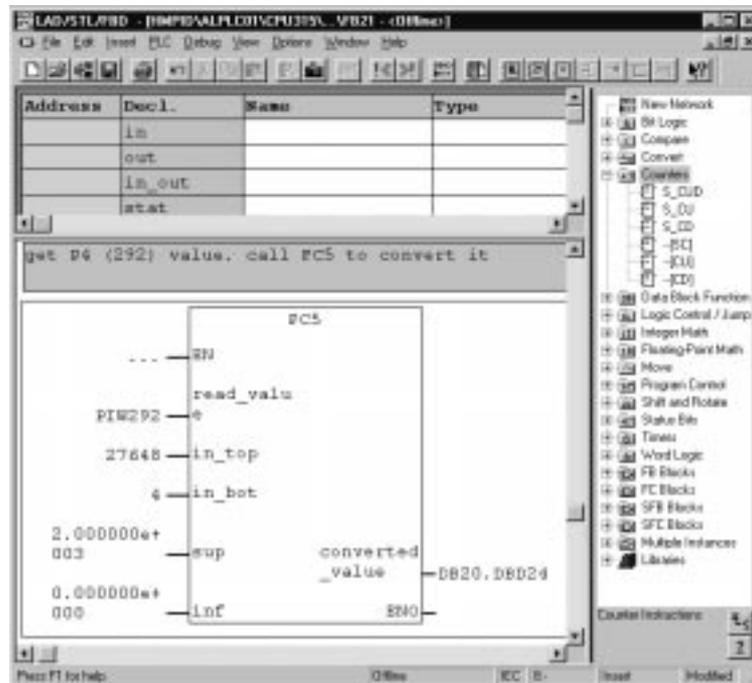


Figure 5: FBD language.

The PLC acquires all the digital and analog inputs and controls the C6F14 liquid distribution following the parameters selected by the user: automatic purge of the radiator, pressure limits, etc. that are set as specified in Table 1. According to the mode selected by the password switches, the commands to activate the valves and the pump are acquired locally from the digital buttons or remotely from the supervisory system.

At the start-up of the PLC a set of defined limits is loaded and all the digital outputs are set to specified values.

2.2.2 Process supervision

BridgeVIEW is a SCADA (Supervisory Control And Data Acquisition) software tool that includes real-time process monitoring, alarm handling, event logging, real-time and historical trending, on-line configuration and also control interfaces in form of OPC clients.

A graphical programming language is provided for the development of the SCADA application and the HMI (Human Machine Interface) interface.

BridgeVIEW has a tag-based architecture. A tag is a connection to a physical I/O point or a derived parameter and is acquired by Servers. An event is anything that happens to a tag or to the BridgeVIEW engine in general (Figure 6).

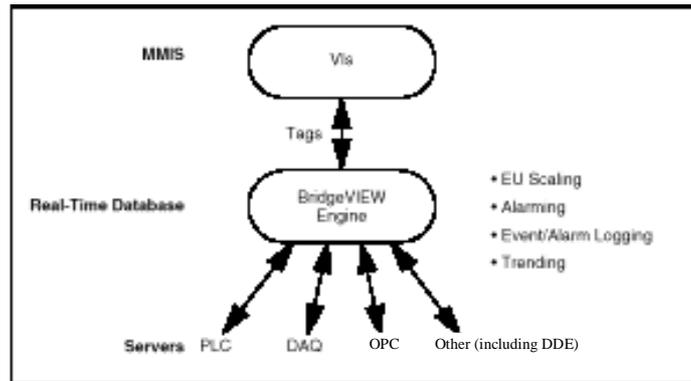


Figure 6: BridgeVIEW architecture.

The BridgeVIEW Engine is the heart of the system. It is the interface between the Servers and the HMI. The Engine exchanges tags with the user process and parameter values with the Servers via input/output queues. It updates a RTDB (Real-Time Data Base) each time a tag value changes by more than its dead-band and logs possible events (alarm events or operator events). The engine, runs as a separate task completely independent from the HMI application and the Servers.

The supervisory process implemented with BridgeVIEW includes functions like:

- logging and archiving facilities to store and retrieve parameter values
- an alarm handler facility
- an access control mechanism based on user/password protection
- Human Machine Interface (HMI) for operator access with synoptic displays of the states of the instrumentation, the values of the parameters and interactive control of actuators like valves and switches.

2.2.3 OPC

OPC is an acronym for OLE[12] for Process Control and is used as a standard interface for communication in automation engineering. OLE includes the component model of Microsoft. The OPC interface is the specification of a uniform and vendor independent software interface based on OLE. It was developed as an industrial standard by leading firms in the field of automation with the support of Microsoft.

Three objects are included in an OPC server: the OPC Server object, the OPC Group object and the OPC Item object (Figure 7).

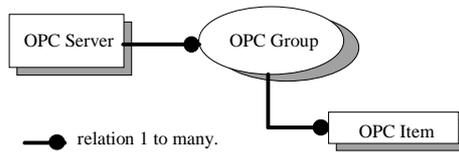


Figure 7: OPC object relationship.

The OPC Server object holds information like server status, version, etc. It contains the OPC Group objects and provides the functionality to an OPC client to create and manipulate OPC Group objects. An OPC Group object holds the group object information and handles the included OPC items. Within each Group, the client can define one or more OPC Items. This allows the clients to organize the data they want to access and provides a way to subscribe to a list of items. The OPC Item object represents connections to data sources within the server. Associated with each item is a Value, Quality (of the value), Time Stamp attribute and a unique ID (Item IDentificator).

3 HMPID liquid distribution prototype control system

Figure 8 shows the hardware architecture of the prototype. Temperature sensors, pressure gauges, electropneumatic valves and pump are connected to the analog and digital input and output modules that are mounted in the same rack as the PLC S7 CPU.

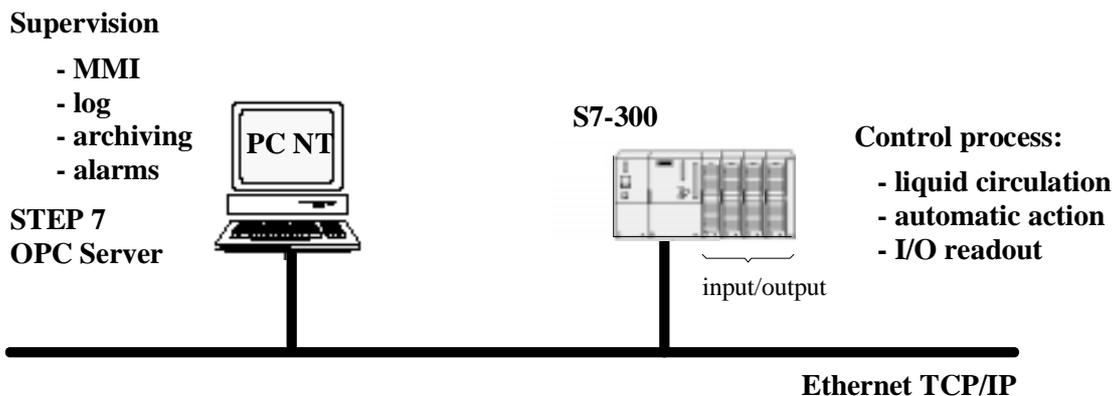


Figure 8: The HMPID hardware architecture.

A PC running Windows NT 4.0 is used as platform for BridgeVIEW, STEP 7 and the SIEMENS OPC Server.

Table 2 gives a list of the components off the shelf for the PLC system that have been installed for the control of the liquid distribution.

Table 2: HMPID items list.

process control	quantity	comments
power supply (5A)	1	
CPU type 315	1	processor module
CP 343-TCP	1	Ethernet interface card
rack mounting	1	
IO Modules		
AI 8x12Bit	2	8 input channels, 12 bits
DI16xDC24V	1	16 input channels 24 V for buttons.
DO8xRelais	1	8 output channels with relays for pumps and electric valves
SM371 simulation module	1	Simulation module used as password selector
software		
STEP 7	1	PLC programming tool
NCMS7 Ethernet	1	run-time library for the CP 343-TCP
SOFTNET IE S7 Basic	1	S7 function library for PC
OPC Server	1	SIEMENS OPC Server

3.1 Process control Software

The application running in the PLC consists of FBs, FCs, DBs and OBs that were created and assembled with the FBD language. The liquid distribution process control was constructed from sub-programs modules (Figure 9). Extensions of the system with additional elements like radiators, headers, etc. can, therefore, be easily implemented. The structure of subsystems is shown in Figure 10.

All sensors and actuators are directly connected to the SIEMENS input/output modules. The readout and the closed loop control are executed in the PLC. The conversion into engineering units is handled by a FC.

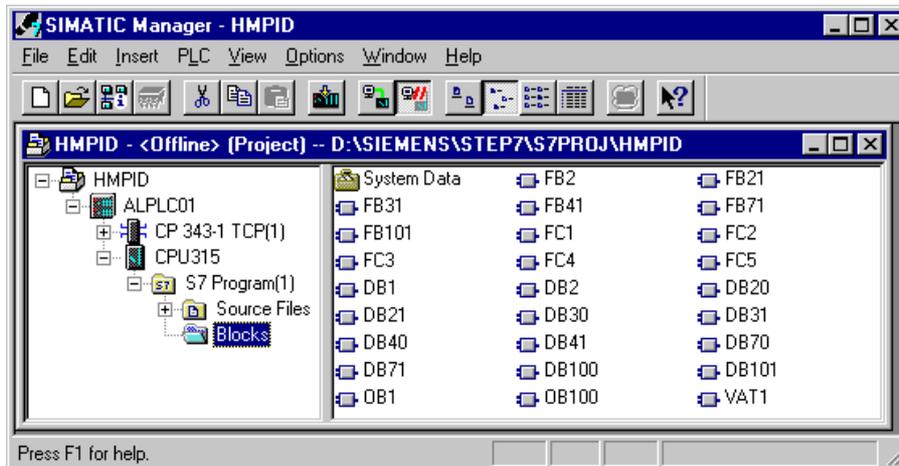


Figure 9: HMPID program.

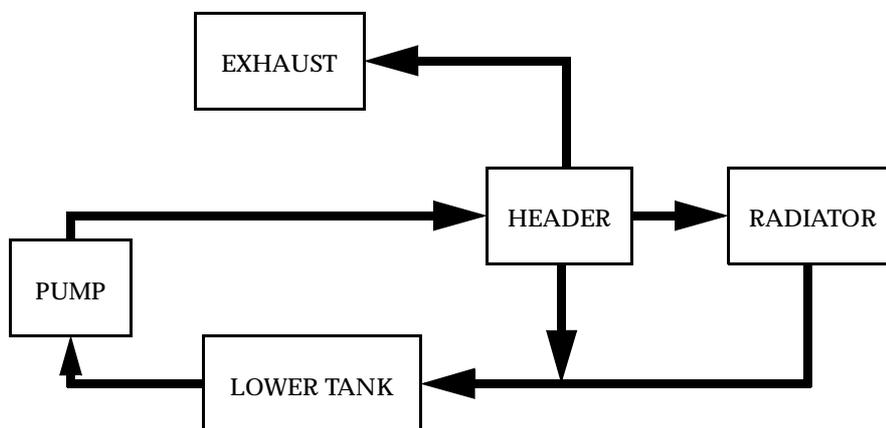


Figure 10: HMPID process architecture.

Each sub-module is connected to defined sensors and actuators:

- MAIN sub-module: filters the commands either locally from buttons or remotely from BridgeVIEW according to the password set.
- PUMP sub-module: handles the start/stop of the pump, reads P4 pressure, evaluates the conditions for the pump.
- LOWER TANK sub-module: reads P2 pressure gauge.
- HEADER sub-module: handles the activation/de-activation of the electro-pneumatic valve Vrd for filling the header tube.
- RADIATOR sub-module: handles the open/close of the electro-pneumatic valves: Vv to purge and Vrr to fill the radiator, reads the pressure P6 and the temperatures T1, T2, T3, T4.
- EXHAUST sub-module: reads P9 pressure gauge.

State transition diagrams have been defined in each sub-module for the automatic control action as described in Table 1. The transitions are triggered by operator commands or by events generated by the PLC (e.g. an overpressure inside the pipe stops the pump).

At start-up of the PLC, a user defined set of limits is loaded and all the outputs are set to default value.

3.2 Process supervision Software

The process supervision was developed with BridgeVIEW. Several types of views implemented as VIs (Virtual Instruments) have been developed for the HMI:

- an overview (Figure 11) is always displayed to select the different radiators, the main settings of the liquid distribution and historical trending
- radiator views (Figure 13) are accessed from the overview. They display information about the liquid distribution in one radiator, like status pressure and temperatures and allow interaction with the process.
- real-time trends (Figure 12) and historical trends (Figure 14) display temperatures and pressures for one radiator. They are accessible from the radiator view by buttons or from the menu bar.
- different panels to modify the process parameters (time-outs, limits of pressures, user password, etc.)

There are two kinds of panels: a panel for global settings (Figure 15), called from the overview, to modify the settings for all radiators, and a panel for radiator settings (Figure 16), called from a radiator view, to modify settings for one specific radiator.

All views have been designed with the BridgeVIEW symbol library. G routines were used to implement the navigation between views, to access the RTDB (Real Time Data Base) and to perform the necessary arithmetic and logic calculations.



Figure 11: The overview VI with active alarm in radiator 1 view.

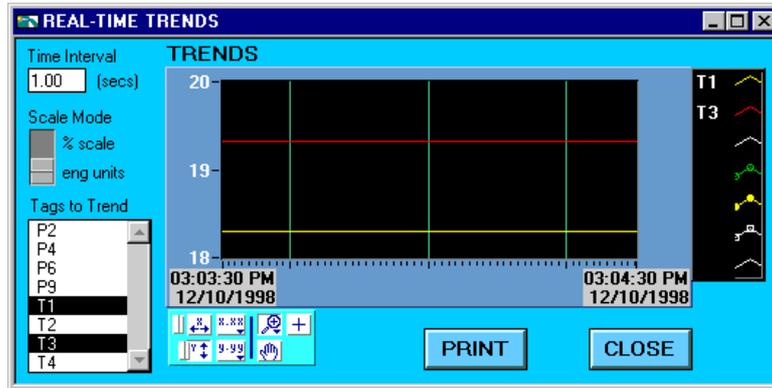


Figure 12: A real time trend view.

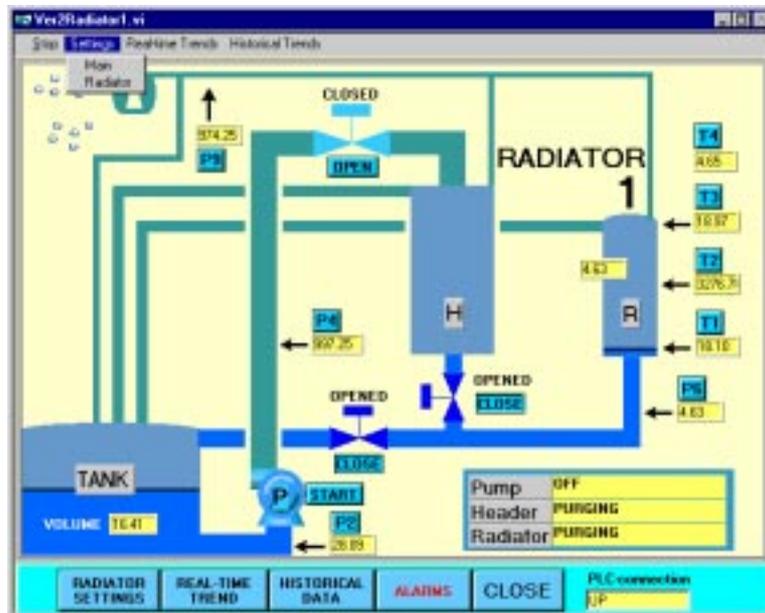


Figure 13: A radiator view.

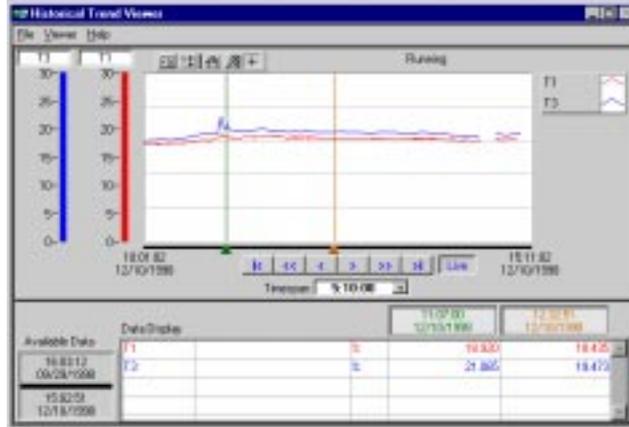


Figure 14: A historical trend view.



Figure 15: Global settings panel.



Figure 16: A radiator settings panel.

When the SIEMENS OPC Server loses the connection with the PLC all the OPC Items have the QoS (Quality of Status) flag equal to “BAD STATUS”. This alarm is reported to the BridgeVIEW RTDB. The corresponding alarms are then set and the operator is notified of the connection loss with the PLC (Figure 17).

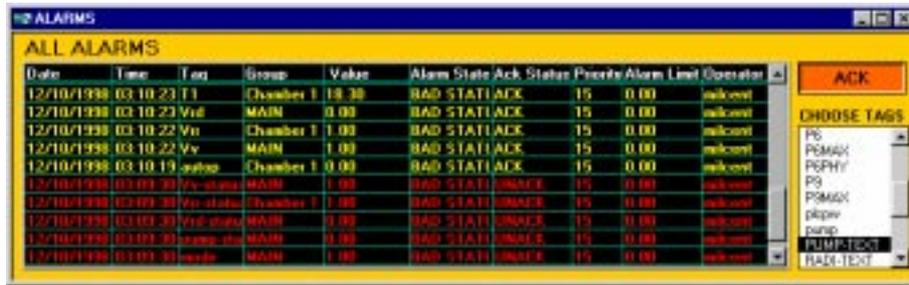


Figure 17: Alarm panel.

The BridgeVIEW archiving facility is based on tags. By default, the archiving is active on start-up and can be stopped by an operator with the appropriate access rights. Archived data can be seen in the BridgeVIEW Historical Trend Viewer (Figure 14). To help the operator, predefined trends have been attached to buttons that are located in the vicinity of the relevant parameters in the radiator views (Figure 13).

To protect the process and the supervisory environment the standard BridgeVIEW access security has been used. Two levels of users have been created: Observer and Expert. By default the user is logged in as Observer at start-up of BridgeVIEW. Observer allows only read access and Expert gives total control for all parameters and settings (start/stop the pump, open/close the electric valves, modify the settings, etc.).

The BridgeVIEW administrator privileges are attached to the Expert user.

3.3 OPC

SIEMENS provides an OPC Server running under Windows NT to communicate with the PLC via PROFIBUS or Ethernet. It allows access to the following items: data blocks (DB), inputs (I), outputs (Q), memory bit (M), timers (T) and counters (C).

BridgeVIEW includes an OPC client that can communicate with any OPC Server. Each BridgeVIEW I/O tag (Figure 18) created is assigned to a group which is automatically mapped to an OPC Group in the OPC Server with the same attributes (Figure 19). The Item name of the BridgeVIEW tag is the OPC ItemID (Item IDentificator).



Figure 18: A BridgeVIEW tag mapped to an OPC Item.

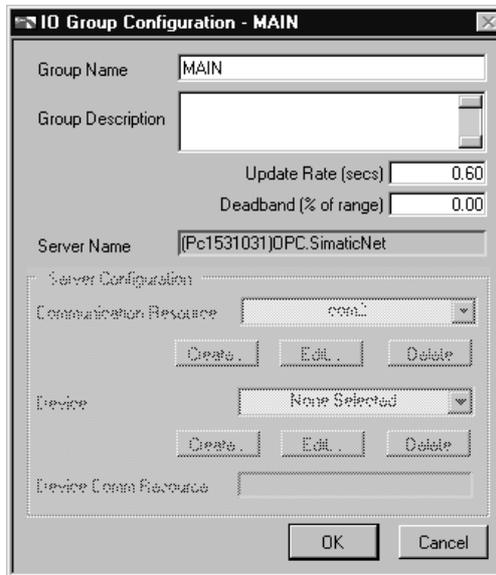


Figure 19: A BridgeVIEW group mapped to an OPC Group.

4 Conclusion

The first version of the HMPID software was released in October 1998 and the final version in December 1998. The software was presented to the ALICE community during the ALICE week in November 1998. A complete and self-contained system has been built and tested on a rather short time scale of 6 man months and with limited resources.

The application has a modular structure that will allow expansion to the full HMPID detector. The software at the level of the control functions in the PLC and also the

supervisory level has been designed to be adaptable to different control strategies and is scalable to larger applications. The system has been tested to the full satisfaction of the users from the point of view of control functionality and the user interface. Improvements and extensions to the functionality are foreseen and will be implemented as result of operational experience.

Acronyms

OPC.	OLE for Process Control
SCADA.	Supervisory Control And Data Acquisition
DCS.	Distributed Control System
PLC.	Programmable Logic Controller
HMPID.	High-Momentum Particle IDentification
RICH.	Ring Imaging CHerenkov

References

- 1 ALICE URL:
<http://www.cern.ch/ALICE/>
- 2 ALICE DAQ, DCS
http://www.cern.ch/ALICE/Projects/Detector_Control_System/
<http://aldwww.cern.ch/>
- 3 First experience with PLC, OPC and BridgeVIEW in the context of the HMPID liquid distribution prototype
ALICE/99-14 Internal note-DCS
- 4 JCOP home page URL:
<http://itcowww.cern.ch/jcop/>
- 5 ALICE HMPID TDR URL:
<http://www.cern.ch/ALICE/TDR/HMPID/>
- 6 National Instrument home page URL:
<http://www.natinst.com/>
- 7 SIEMENS:
<http://www.siemens.de/en/>
- 8 OPC foundation:
<http://www.opcfoundation.org/>
http://www.opcfoundation.org/opc_public_tech.htm
- 9 Fieldbuses recommendation
<http://itcowww.cern.ch/fieldbus/report1.html>
- 10 PLC recommendation
private communication
- 11 PROFIBUS:
<http://www.profibus.com/>
- 12 OLE-COM-DCOM:
<http://www.microsoft.com/activex/default.asp>

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