Řídicí systém pro projekt TOTEM

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Abstrakt

Článek diskutuje možná řešení automatizace experimentálního kompresorového chladícího okruhu pro projekt TOTEM, který je konstruovaný v mezinárodním středisku CERN v Ženevě. Porovnání aplikační architektury ve SCADA systému Experion PKS a realizací v programovém prostředí PVSS II je zásadním rozhodnutí při řešení úkolu. Návrh architektury sběru dat v obou systémech a výběr nejvhodnějšího řešení pro připojení modulů Embedded Local Monitor Board (ELMB) a jednotek PLC do řídicího systému je shrnuto v závěru práce.

Klíčová slova

Řídicí systém, SCADA, kompresorové chlazení, TOTEM

Abstract

Article discusses possible solutions for the automation of the experimental evaporative cooling circuit of the TOTEM project, which constructed in an international center CERN near Genéve. Comparison between the application architecture in SCADA system Experion PKS and implementation in the programming environment PVSS II is a major decision in solving the task. Architecture design of data collection in both systems and selection of the most appropriate solution for the connection of Embedded Local Monitor Board (ELMB) modules and PLCs into the system is summarized at the end of this paper.

Key words

Control system, SCADA, evaporative cooling, TOTEM

1. Introduction

1.1. TOTEM Project

TOTEM (TOTal Elastic and diffractive cross section Measurement) is one of the projects built along the Large Hadron Collider (LHC) at the International centre for nuclear research (CERN), see [1] and [2]. Project is divided into three main subsystems– Roman Pots (RPs), Telescope 1 (T1) a Telescope 2 (T2).

Roman Pots detectors use experimental measuring technique firstly introduced in the early 70th at Rome, see [3]. The detectors are housed in twenty-four vacuum vessels that are placed along the LHC at the Intersection Point 5 (IP5), which is common to CERN CMS project. The vessels are split in four groups of six, with each group located in distance from IP5 as is depictured in Figure 1.

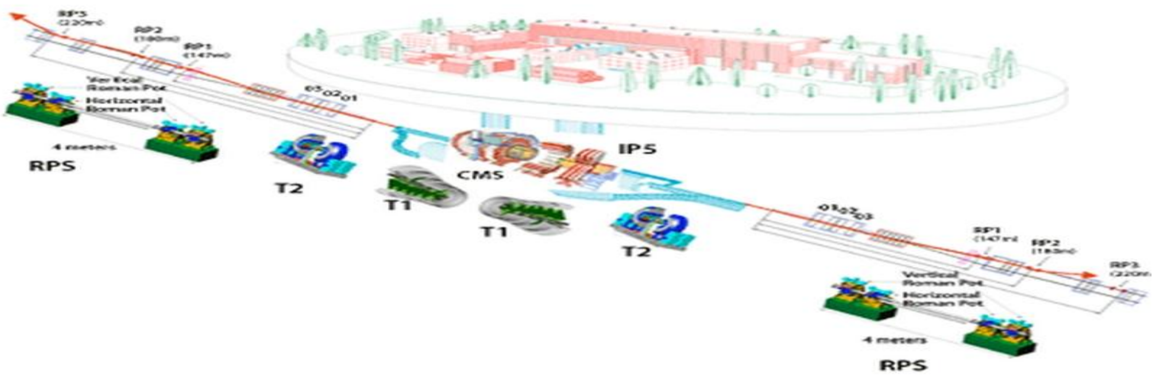

Figure 1 *- TOTEM Experiment layout, adopted from (8)*

1.2. Roman pots cooling plant

Roman Pots operation requires temperatures below 0°C. Typical temperature set-point is around -20 °C. Thus, a cooling plant was constructed to provide such conditions. The Roman Pots Cooling Plant (RPCP) is located in the underground service cavern at IP5. The cavern houses all control elements. The place was chosen as it grants full time personnel access during the LHC operation.

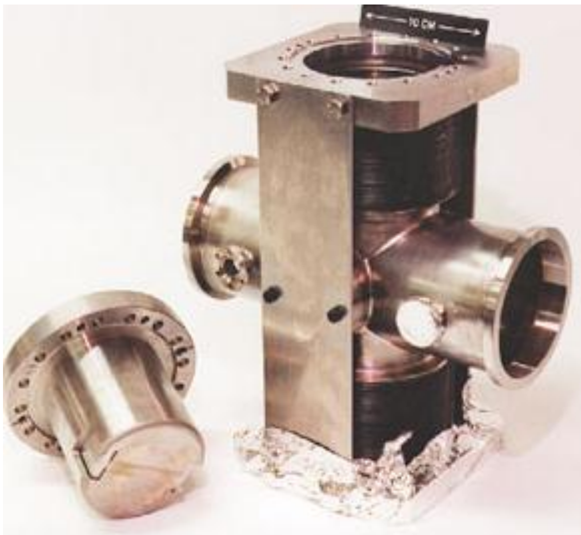

Figure 2 *– Roman Pot*

The plant is based on two stage evaporative cooling principle. During the cooling process, the pre-chilled refrigerant is supplied under the high pressure in the liquid state into the capillary located inside the RP volume. The pressure drop introduced post-capillary causes evaporation of the coolant. Thus, cooling is enabled along the evaporator.

RPs heat generation is up to 800W of the heat in total. Each can be operated independently from the others and its heat load may vary over the full scale (0-100%) depending on the RP state. Thus, the cooling is split into four separate cooling loops that correspond with the separation of the RPs.

A manually operated TESCOM pressure regulators and back-pressure regulators are currently used for the control of the coolant inlet pressure and vapor pressure. Such solution does not allow precise control of the cooling process and it requires presence of the attendants at place.

Stable cooling process is essential for safe operation of the Roman Pots sub-detectors. Thus, the TOTEM cooling plant requires a reliable control system that would prevent damage of the RPs and the cooling plant itself. The cooling plant control system is based on SIEMENS S7-200 PLC low-level controllers that are monitoring all cooling plant sensors, evaluating the cooling plant status and if necessary take automatically appropriate action (e.g. turn off the cooling). The status of the operation is communicated to the high level control via the SIEMENS Communication PLC, which doesn’t have access to the action elements (can´t be used for the remote control). The high level control communicates with low-level controllers over the Simatic OPC server.

1.3. TOTEM control system

The TOTEM detector control system (TDCS controls three sub-detectors (Roman Pots, T1 and T2), environmental monitors, high voltage and low voltage power, and cooling plants. The detail description of TDCS can be found in [3] and [4].

The TDCS was implemented in the PVSS II SCADA system. The software functionalities required for tasks related to the control and monitoring of the TOTEM project were split into modules of PVSS code. Such design gives opportunity to include new modules and functionalities. TDCS deploys tree, where each branch represents one sub-detector and its supporting components. The high level control is provided by six servers, where two cooperating computers manage one sub-detector.

1.4. Goal of the project

Our goal is to design a control subsystem architecture that would enable automate control of whole RPs cooling process. The newly designed control system must be able to drive the pressure of the liquid entering the cooling loop and the vapor evaporative pressure according to the various sensors readings. The project was made as a part of [11] and it is in detail described there.

2. Motives for upgrade

The cooling is a significant part of a TOTEM project inevitable for a RPs operation. The amount of heat generated by the RPs inner electronics may vary in a full scale during the RPs operation. The fast temperature changes of the electronics may significantly reduce its lifetime or in the worst case cause their immediate destruction. Thus, the cooling circuit control system must be able to take action if needed. In other words, the set-points of the process variables that determine the cooling process conditions need to be editable remotely. The future upgrade of the RPCP should add this functionality to the TDCS.

3. Instrumentation Requirements

The new system must accommodate over eighty sensors of different types – temperature sensors (PT100, PT1000, Capton coated NTC), pressure transducers (V and mV output).

It must also generate field output action signal for new coolant pressure actuators. The control signal type is not priory specified, thus control system must be able to calculate emit both analog and digital signal.

Finally, system integration procedure into the TDCS must be resolved. All process variables must be available in TDCS as the data-base and gate for the remote control is foreseen to be common for both systems.

4. Control system architecture

Two different approaches were considered – centralized control system (CCS) and distributed control system (DCS). The selected CS architecture type determined layers of desired solution. DCS has typically a Supervisory Control And Data Acquisition (SCADA) system running on the top of a control hierarchy. SCADA then communicates with the industrial process through set of I/O modules. I/O modules are than connected directly to the sensor array and actuators. This means that the pressure sensors readings from RPCP are communicated through I/O module (e.g. PLC) to SCADA, where can be calculated action intervention. The calculated value is then send back to the actuators, which adjusts the pressure set-points. This system is depicted in Figure 3. The search for the required SCADA component is described in Chapter 5.

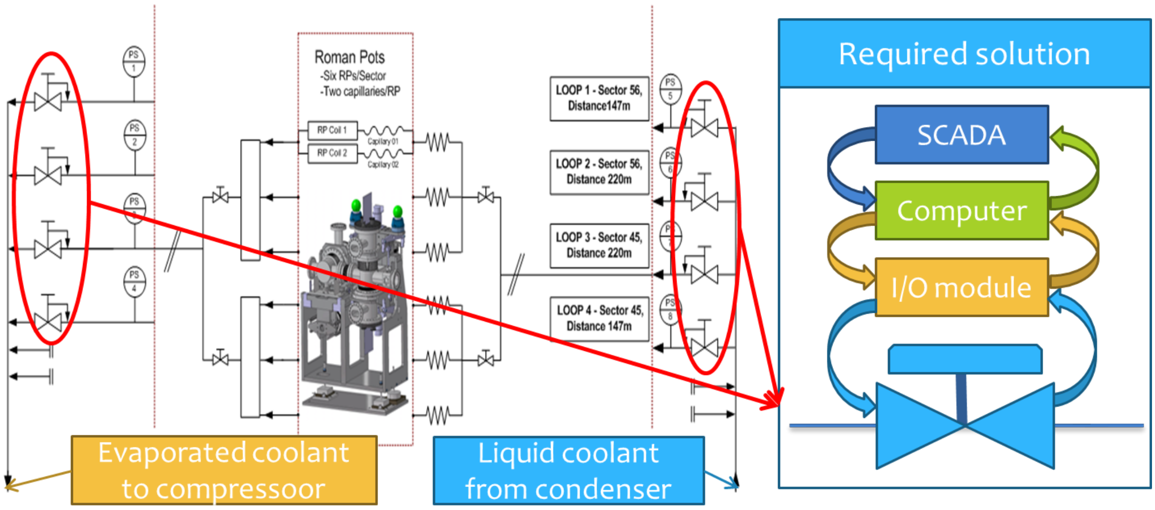

***Figure 3** – Control system architecture*

5. Component selection

Two different approaches were available:

a) Use similar software and hardware technologies to the ones of CMS or other LHC experiments and modify them if necessary.
b) Utilize completely different technologies and provide a compatible communication interface.

Thus, it was decided to compare one commercial solution that is not being use in CERN projects and one CERN supported solution.

The main analyzed parameters used for the selection of the components aside the natural restrains listed in Chapter 3 were:

- Price.
- Scalability.
- Communication capabilities.

• Reliability.

5.1. SCADA system comparison

The goal of the SCADA products comparison was the selection of the most appropriate software base for the implementation of the cooling plant control system. The considered products were Honeywell Experion and ETM PVSS II, see [9] and [10].

Experion

Experion is a commercial SCADA system by Honeywell (www.honeywell.com). It is a server based solution. All hardware controllers and external data sources communicate with Experion server over LAN via TCP/IP protocol. EPKS is based exclusively on Windows 2003 platform. The server redundancy option is supported with server A and server B as a hot standby back up pair. The cluster of servers can consist of 20 servers. All data from all servers can be accessed by up to 40 simultaneously connected client stations.

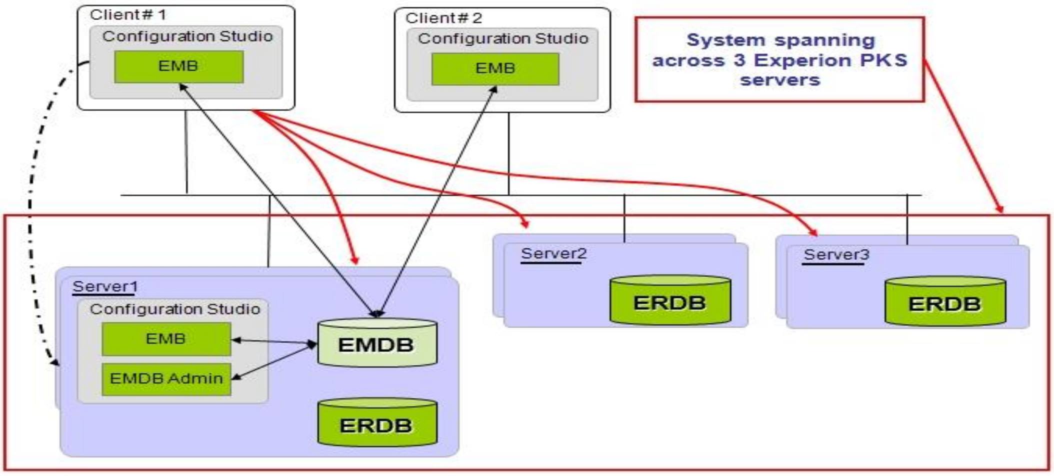

Figure 4 *– Experion data-bases structure overview*

One server can house up to 65000 data containers for points. Each measurement or communication channel definition takes one point in this data-base. All points and parameters, even operator commands can be archive stored. Operator commands and alarms are stored asynchronously and server has live FIFO list of 100 000 events, which occurred recently in the system. For all process values, archiving can be defined, fastest update rate for history is 5 seconds.

Field devices – measurement instruments or actuators - are typically accessed through Industrial controller of C200/C300 series. More recent is C300 controller provides fast deterministic scan rate between 50 and 500ms, for special applications also a fast version with 20ms is available. Special feature of C300 is guaranteed scan time, deterministic program evaluation and load estimate priory to load.

Honeywell delivers the controller C300 with proprietary I/O cards of AI, AO, DI and DO type. C300 controller and all I/O modules have the option to be redundant, which provides a smooth failover in case of hardware failure. The AI and AO card reads out data in 4-20mA HART format. Up to 64 I/O cards can be attached to C300 on two I/O links (Honeywell proprietary bus for I/O readout). Fieldbus devices are communicating with

C300 over TCP/IP via FIM4 module, which can serve up to 64 FIELDBUS devices on 4 branches.

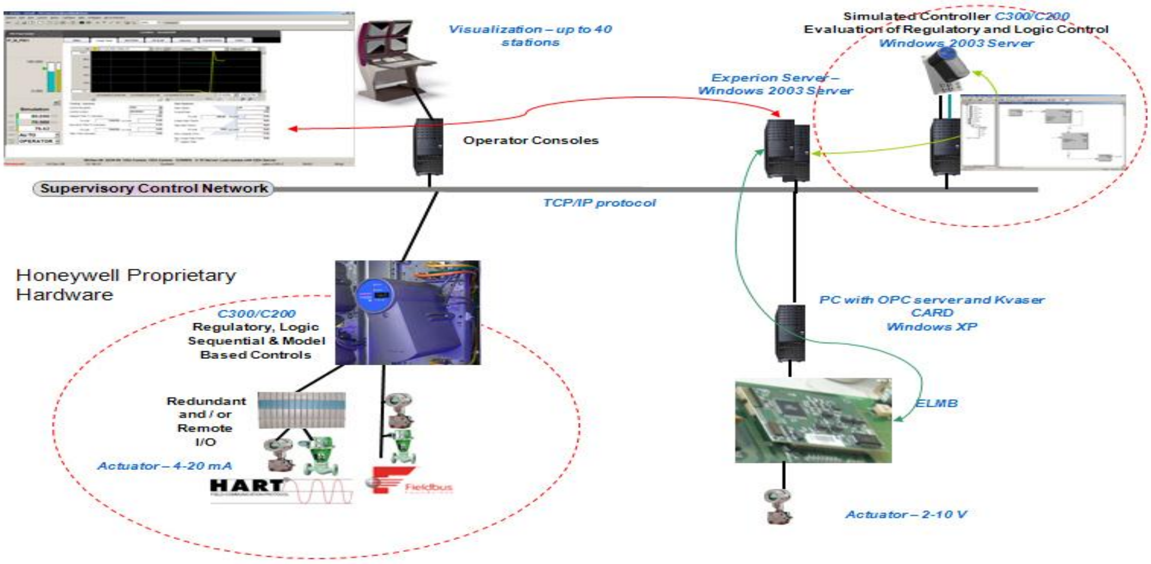

Figure 5 *– Experion connection to the I/O module*

In those cases, when only evaluation of sequences or logic control is required, there exists a C300 simulation option. A special PC with Honeywell dedicated software would run emulation, which processes data like C300 controller. Such option can be successfully used, when you need to control process over communicated channel. The embedded function for PID control available in C300 can process input signal and generate output, all alarming and history can be configured via same approach as for hardwired I/O channel. Greatest advantage is that a developed program can be transferred into real C300 processor.

In those cases different than Honeywell hardware is going to be used there exists an option that Experion server can communicate with this hardware over OPC of Modbus. For such purposes there exists a retouched data-base in Experion, which maintains this communication, called RTDB (Real Time Data-base). Each server is able to read/write up to 65000 points with defined sampling rate from 2s. A special software component in Experion server, called OPC integrator provides transfer of values between points in RTDB and remote OPC server. In the Figure 5, the goal is to read out and evaluate process values coming from CAN bus standard device. For such purpose, there must be a computer server with CAN Open OPC server running, which would publish values from field. The OPC integrator would mirror these values from OPC server into points on the server or in the simulated C300. In the C300, the collected real time data is compared with alarm limits and also control action is derived. Embedded functions for PID control or even blocks for singe loop model predictive controls will generate the output signal, which is transfer via OPC back into field. Typical response time of this solution is around 5 seconds (3 seconds takes OPC transfer + 2 seconds takes value processing) and sampling rate is around 2 seconds (one direction time for OPC).

At least one computer is necessary for the Experion based control system. The computer must be a rack server manufactured by DELL company (e.g. DELL PowerEdge 2970), because only such computers are supported by Honeywell company. The demands on hardware are growing, when the C300 simulation or OPC server is necessary, detail requirements are enlisted in the Table 1. The price of the DELL rack server is approximately 12000 CHF and the price of the desktop computer is 1100 CHF (based on price list from [9]).

***Table 1** – Experion hardware requirements*

Computer usage	Operational system	Computer type	HDD space	OM Size
Experion server	Windows 2003 server	DELL 2970	30 [GB]	3 [GB]
C300 simulation	Windows 2003 server	DELL 2970	30 [GB]	3 [GB]
OPC server	Windows XP	Vostro220	5[GB]	1[GB]

Process Visualization and Control System

A SCADA system named PVSS II (meaning Process Visualization and Control System II) produced by the Austrian company ETM. PVSS was chosen by all LHC experiments as the supervisory system of the corresponding DCS systems and it is now recommended as a CERN – wide SCADA system. The main advantages are:

- Scalability - it can work with systems of any size (it has no limitation in the number of connected devices).
- Versatility - it can be expanded with modules written in the C++ and its inner scripting language (Control Programming Language) has also C++ syntax.
- Built-in support of the networking over TPC/IP.
- Low hardware requirements – it can run on any computer with Windows XP.
- Easy access to internal variables.
- Multiple operational system support (Windows and Linux).

The PVSS SCADA system is composed from central components – blocks - organized in four layer hierarchy, see Figure 6. The first - lowest - layer consists from drivers that are provides the direct contact with the field devices. Data archiving (data-base manager) and reaction on the communicated events (event manager) are located in the second layer. The C++ programs and Control Programming Language scripts can be lunched in the third layer. The top layer is reserved for the user interfaces.

Each PVSS II system has always one event manager and one data-base manager. It can have multiple drivers (connected to the hardware), running scripts or user interfaces. Each of these items can run on a separate processor if required.

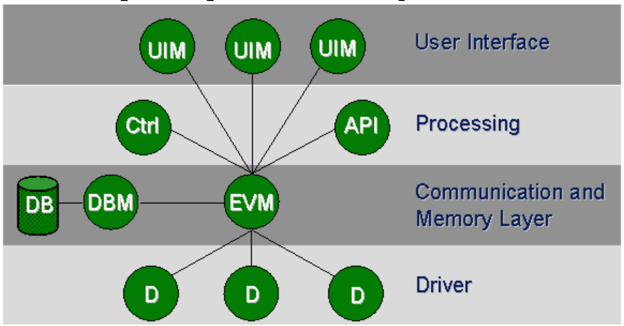

***Figure 6** – PVSS system hierarchy, adopted from (10)*

Several PVSS II systems can be connected together to enhance the capabilities and offered resources and to distribute the load, see Figure 7. A system can be spread over several PCs or more than one system can be run on one PC. This design makes PVSS II highly scalable and allows independent development of control system subparts.

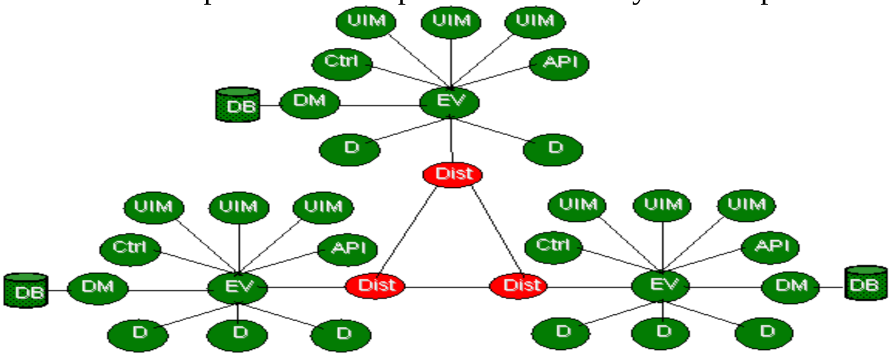

Figure 7 *– PVSS distribution of the system components, adopted from (10)*

All data (parameters, variables, communicated values, etc.) are organized into the structural units called Data Points. The data points have tree hierarchy consisting from any data types (numbers, text strings, etc.). Each data point stored on a PVSS machine must have locally unique name (two data points can have same name but they must be stored in different systems).

The system of the data archiving can be specified for each data point. The data can be stored asynchronously after the value in the data point changes, synchronously with any synchronization time or in combination. The data can be stored locally in the SQL based data-base built in the PVSS, or they can be communicated to the external data-base (e.g. Oracle data-base).

The PVSS have built in support for connection with OPC server, which can run on the same computer as the PVSS system. After the server is configured in the PVSS and lunched the communication is automatically established by PVSS OPC client. The values from OPC server are then copied into corresponding data points and vice versa. The PVSS offers also the simulator of the OPC server that can be used for the testing purposes. The PVSS system architecture is not limited in the number of connectable devices over OPC – the only limitation is given by used hardware.

The PVSS II system runs on Windows and Linux and one can mix both operating systems even within a single PVSS II system. Thus the only requirement on the computer is the ability to run any Windows (e.g. Microsoft Windows XP) or Linux system (e.g. Ubuntu 9.0) and to have enough free hard disk space for the PVSS installation – 2 GB.

5.2. SCADA system selection conclusion

Both evaluated SCADA systems were found as very powerful and usable as a CS for the TCP – they can both provide connectivity for any PLC or ELMB unit over the OPC server. The basic functionality of both systems is almost the same, but the Experion system moreover offers a complete solution for control system including PLC, action elements and tools for the PID control. The PVSS is on the other hand more scalable and resources requiring solution with wide support at CERN. The data gathered in the analysis are summarized in Table 2.

Table 2 – SCADA systems comparison

Property	SCADA System	
	Experion	PVSS II
Built-in data-base	yes	yes
Price	License price depends on data-points number	Free (in CERN)
Hardware requirements	High (min. 2 rack servers)	Low
ELMB supported	Yes	Yes
PLC supported	Yes, but only Honeywell made	Yes
PLC Virtualization	Yes	No
Built-in FSM support	Yes	No
Data-points limit	No	No
Minimal data-point refresh time using the OPC	More than 5 s, non-deterministic	1 s, deterministic
Redundancy supported	Yes (system may be mirrored on another computer)	Yes (System may be duplicated even on the same computer)
Distributable over multiple computers	No	Yes
Supported OS	Windows 2003 Server	Windows 2000 and higher, Linux
CERN support	No	Yes

The PVSS II was after considering all available information selected as the most suitable SCADA system for the cooling plant control system. The main reasons for the selection are:

- Lower hardware requirements.

(Experion requires DELL rack server with Microsoft Windows 2003, PVSS can be on the other hand started on any computer with Windows or Linux operation system)

- Higher scalability and easier redundancy.

(PVSS systems can create any architecture with built in communication over the LAN, thus the final system can be easily modified and any redundancy can be added.)

- CERN – wide usage and support of the PVSS II.

6. Conclusion

The project task was to select the most suitable SCADA for the CS that will be used for the future upgrade of the RPCP. The restrictions for the selection process were given by both hardware setup of the cooling plant and the architecture of already used TDCS system. Two commercial products were analysed in detail – Experion produced by Honeywell and PVSS II from ETM (SIEMENS Company). The research was focused mainly on the hardware requirements, connect-ability into TDCS, scalability, data management, speed of the readout, FSM implementation and price of the solution. Considering all acquired facts that are summarized in Section 5.2 the PVSS II product was chosen as a best fit for the RPCP upgrade.

Literature

1. G Anelli et al.: *The TOTEM Experiment at the CERN Large Hadron Collider*, The TOTEM Collaboration, S08007, Institute of physics publishing and SISSA, 2008, Vol. 3., http://stacks.iop.org/1748-0221/3/S08007
2. TOTEM: *The TOTEM experiment detector page*, The TOTEM experiment site. [Online] [Cited: 25 11 2009.], http://totem-experiment.web.cern.ch/totem-experiment
3. Oriunno, Marco, et al., et al.: *Design and prototype studies of the TOTEM Roman pot detectors*, Nuclear instruments & methods in physics research section A-Accelerators spectrometers detectors and associated equipment, February 2007, Vol. 581, Issue 1-2, p. 499-503
4. Rodríguez, Fernando Lucas**:** *Design, Development and Verification of the Detector Control System for the TOTEM experiment at the CERN LHC*, Sevilla, Universidad de Sevilla, 2009, CERN-THESIS-2009-046
5. Rodriguez, F. Lucas, et al., et al.: *-Big.Brother- The TOTEM Detector Control System*, Genéve, CERN, 2009
6. CERN**:** *Fluid data*, TS/CV Detector Cooling Section home page, [Online], [Cited: 6 12, 2009.], http://detector-cooling.web.cern.ch/Detector-Cooling/data/C3F8_Properties.pdf
7. Ellis, George: *Control System Design Guide: Using Your Computer to Understand and Diagnose Feedback Controllers*, San Diego, Elsevier Academic press, 2004, ISBN 0-12-237461-4
8. DELL: *Dell servers, storage & network service*, Dell home page, [Online], [Cited: 10 27, 2009.], http://www.dell.com/us/en/enterprise/enterprise/ct.aspx?refid=enterprise&s=biz&cs=555&~ck=mn
9. ETM: *ETM home page*, [Online], [Cited: 4 15, 2009.], http://www.etm.at
10. ITCOBE***:*** *PVSS Introduction for Newcomers*, The Large Hadron Collider beauty experiment home page, [Online], [Cited: 3 22, 2009.] http://lhcb-online.web.cern.ch/lhcb-online/ecs/PVSSIntro.htm
11. Vítek, Michal**:** *Monitoring and control system for the TOTEM project*, Diploma thesis, Prague, CTU in Prague, 29.1.2010