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A PVSS Application for Monitoring the Start-up of the Super Proton Synchrotron After Major Breakdowns

Diplomarbeit

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Eingereicht von

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EIDESSTATTLICHE ERKLÄRUNG

Ich erkläre hiermit an Eides statt, dass ich die vorliegende Arbeit selbständig und ohne fremde Hilfe verfasst, keine anderen als die angegebenen Quellen und Hilfsmittel benutzt, mich auch sonst keiner unerlaubten Hilfe bedient habe und diese Diplomarbeit bisher weder im In- noch im Ausland in irgendeiner Form als Prüfungsarbeit vorgelegt habe.

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KURZFASSUNG

Supervisory Control and Data Acquisition Systeme (SCADA-Systeme) werden heute weitreichend für die Überwachung und Steuerung technischer Anlagen der Europäischen Kernforschungsorganisation (CERN) eingesetzt. Eine Vielzahl verschiedener SCADA-Systeme dienen dabei der Überwachung elektrischer, kryogenischer und anderer Systeme, sowie der Steuerung und Kontrolle von Teilchenbeschleunigern und physikalischen Experimenten.

Diese Diplomarbeit behandelt die Entwicklung einer auf SCADA-Technologie basierenden Softwareapplikation für zwei der zentralen Kontrollräume des CERN. Zweck der Anwendung ist die Überwachung des Super Proton Synchrotron (SPS), dem zweitgrößten Teilchenbeschleuniger des Labors, während seines Neustarts nach schweren Pannen. Einer CERN-Empfehlung Folge leistend, basiert die Anwendung auf PVSS II, einem kommerziellen SCADA-Produkt, das die derzeit im Einsatz befindliche heterogene Komponentenarchitektur zur Überwachung von SPS-Equipment ablösen soll.

Die Installation des SCADA-Produktes als redundantes und verteiltes System, mit dem Ziel maximale Verfügbarkeit und Datenaustausch mit anderen PVSS Systemen zu garantieren, ist einer der Kernpunkte dieser Arbeit. Um mit SPS-Hardware zur Laufzeit kommunizieren zu können, musste ein PVSS Treiber entwickelt werden, der unter Zuhilfenahme einer existierenden Middleware den Datenaustausch mit verschiedenartigen Geräten rund um den Teilchenbeschleuniger ermöglicht. Das objektorientierte Design und die C++-Implementierung dieses Treibers werden im Detail diskutiert. Besonderes Augenmerk wurde auch auf die Implementierung der Benutzerschnittstelle der Anwendung gelegt, jenem Teil des Systems mit dem Operatoren auf täglich Basis arbeiten werden. Ein erster Prototyp der Benutzerschnittstelle, bestehend aus einigen PVSS Panels, wurde in enger Zusammenarbeit mit den betreffenden Kontrollraum-Operatoren entwickelt. Die Ergebnisse dieser Zusammenarbeit werden im Rahmen dieser Diplomarbeit präsentiert. Zusätzlich zur Applikation selbst musste ein off-line Datenbanksystem zur Verwaltung statischer PVSS Konfigurationsinformationen entwickelt werden. Der Entwurf einer Integrationsstrategie für existierende Konfigurationsdaten, das Design einer relationalen Datenbankstruktur zur Speicherung dieser Informationen und die Implementierung von Perl Scripts und PL/SQL Prozeduren zum Datenimport und –export werden in dieser Arbeit präsentiert.

ABSTRACT

Supervisory Control and Data Acquisition (SCADA) systems are widely employed in monitoring and controlling technical facilities at the *European Organization for Nuclear Research (CERN)*. Various kinds of SCADA systems are used for the supervision of electricity, cooling, cryogenics and other systems as wells as for the control of the laboratory's particle accelerators and high-energy physics (HEP) experiments.

This thesis is concerned with the development of a software application for two of CERN's main control rooms, for monitoring the start-up of the Super Proton Synchrotron (SPS), the laboratory's second largest particle accelerator. Following a CERN recommendation, the application is based on PVSS II, a commercial off-the-shell SCADA product that will replace the heterogeneous component architecture currently used for monitoring SPS equipment.

The set-up of the SCADA system in a redundant, distributed and scattered manner in order to guarantee high dependability and the possibility of doing data exchange with external PVSS II systems is a central issue of this work. A PVSS Driver Manager to SL-Equip, a middleware allowing data exchange with heterogeneous remote devices located around the accelerator, is developed in order to communicate with SPS hardware. The object-oriented design and the C++ implementation of this driver are discussed in a detailed manner. Special attention is paid to the design and implementation of the application's user interface, for this is the part of the system that the control rooms' operators will be confronted with on a daily basis. A first prototype of this interface, consisting of a series of PVSS panels, is developed in close co-operation with the operators concerned. In addition to the application itself, an off-line database system for managing static PVSS configuration information is created. An integration strategy for existing configuration data is developed, a relational database structure for storing the information is designed and Perl scripts and PL/SQL procedures for data import and export are implemented.

THANKS AND ACKNOWLEDGEMENTS

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Of course, I want to thank *Karin Pröll*, my supervisor from the Polytechnic University of Hagenberg for her support during my internship at CERN and while I was writing this thesis.

I also want to express my thanks to *Gregory Curtis*, my English teacher at the Upper Austrian Polytechnic University, who sacrificed his time to correct this work and to improve my sometimes modest style in English.

Especially, I want to thank *Johannes Dirnberger* and *Yann Bieber* who helped me out with countless suggestions during my stay at CERN.

This thesis is dedicated to my family.

Jan Stowisek, August 2001

TABLE OF CONTENTS

1. INTRODUCTION

This thesis is concerned with the development of a software application for monitoring the start-up of the Super Proton Synchrotron (SPS), CERN's second largest particle accelerator. As the title suggests, PVSS, the CERN recommended supervisory control and data acquisition (SCADA) system, will serve as a basis for the application.

This first chapter provides the reader with some background information about the organizational environment in which this thesis was written, roughly outlines the problem to be solved, gives an overview of existing solutions to similar problems and, finally, presents an outlook to the following chapters.

1.1 Organizational Environment

This section starts with a general presentation of the *European Organization for Nuclear Research (CERN)* and its activities, followed by a description of the author's immediate working environment, the Monitoring and Operation (ST/MO) group.

1.1.1 CERN – The European Organization for Nuclear Research

CERN, often referred to as the *European Laboratory for Particle Physics* but officially called the *European Organization for Nuclear Research*, is one of the largest and most important high-energy physics (HEP) centres in the world. Established in 1954 with the aim to provide for European collaboration in nuclear research of a pure scientific and fundamental character, the institute nowadays attracts over 6,000 scientists of more than eighty nationalities. Following its mandate laid out in the CERN Convention, the organization "has no concern with work for military requirements and the results of its experimental and theoretical work are published or otherwise made generally available" [CERN, 1954].

CERN is situated on the border between France and Switzerland, just outside Geneva, a location that symbolises the *international spirit of collaboration* that is one of the reasons for the laboratory's success. From the original 12 signatories of the CERN convention, membership has grown to the present 20 Member States.

CERN's accelerator complex is the most versatile in the world, consisting of a set of ten linear and circular machines. The first operating accelerator, the *Synchro-Cyclotron*, was built in 1954, in parallel with the *Proton Synchrotron (PS)*. The PS is today the backbone of CERN's particle beam factory, feeding other accelerators with different types of particles. The 1970s saw the construction of the *Super Proton Synchrotron (SPS)*, at which Nobel-prize winning work was done in the 1980s. The SPS continues to provide beams for experiments and is also the final link in the chain of accelerators, providing beams for the 27 kilometre long *Large Electron-Positron Collider (LEP)*. CERN's next big machine, due to start operating in 2005, is the *Large Hadron Collider (LHC)*, at which the fascinating quest for the Higgs boson, the last undetected particle of the standard model, will be carried on.

For more comprehensive information about CERN, its accelerator complex, experiments and contributions to the world of high-energy physics, please refer to [WWW-CERN].

1.1.2 The Technical Support / Monitoring and Operation Group

Seeing that CERN is hierarchically organised in divisions, groups and sections, we will take a closer look at the Monitoring and Operation (ST/MO) group, the subgroup of the Technical Support (ST) division the author is working for.

Within the ST division, which has the mandate to provide technical support for accelerators and related experimental areas, including the LHC project, the ST/MO group is responsible for the monitoring and operation of all CERN technical infrastructure.

This activity is covered by four sections that are illustrated in Figure 1-1.

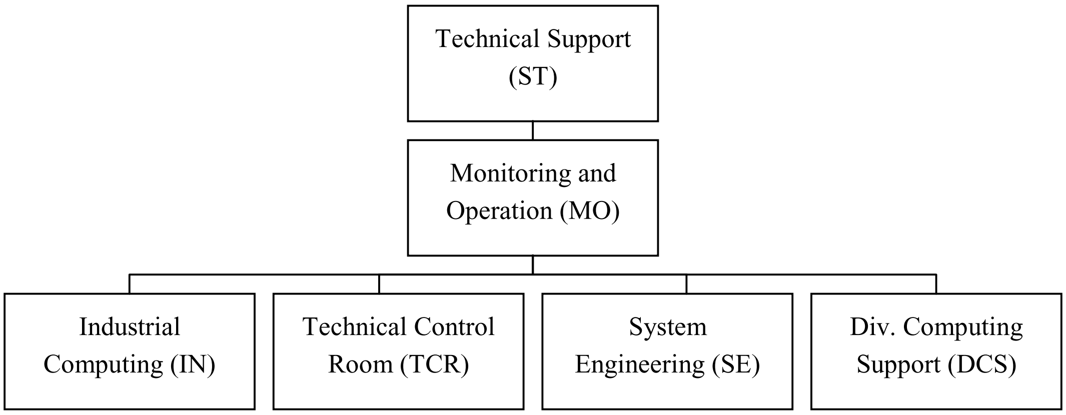


Figure 1-1 How the ST/MO group is embedded in the CERN hierarchy

The *Technical Control Room* (TCR) with its 24h/day and 365days/year operational service supervises electricity, vacuum, demineralised water, cryogenic, safety and control systems and acts as a trouble-shooter in case of breakdowns.

The *Industrial Computing* (IN) section is responsible for the development and maintenance of the control systems for the TCR and the Safety Control Room (SCR).

The *System Engineering* (SE) section is in charge of the development and implementation of the CERN Safety Alarm Monitoring (CSAM) System and for system engineering support on safety-related control systems.

The *Divisional Computing Support* (DCS) section provides Web and desktop support to division members.

This thesis is the result of a co-operation of three of the sections mentioned above: the TCR as a client, the IN section with Peter Sollander as technical responsible and the SE section with Luigi Scibile, as the author's academic supervisor.

1.2 Motivation for the Project

Two coinciding factors have lead to the launch of the SPS Restart Application project:

(1) In the course of the *Gestion Technique des Pannes Majeures* (GTPM) project, a collaboration of the TCR, the Prévessin Control Room (PCR) and the SPS/LEP

Controls (SL/CO) group, a thorough analysis of the functions and logic of the SPS start-up procedure was performed. While the project's main objective was to work out system diagrams, operating instructions and technical descriptions in order to facilitate the restart of the SPS after a major breakdown, it was also decided to develop an application for monitoring the systems involved in the start-up procedure.

(2) PVSS II, an industry SCADA system developed by the Austrian company ETM, was chosen as the CERN *recommended SCADA system for all LHC experiments*. As a consequence, the ST/MO group determined to migrate its existing control systems, notably the Technical Data Server (TDS), to PVSS. The SPS Restart Application should become the group's first application to be implemented using PVSS in a technical services context.

The SPS Restart Application project was launched as a subproject of GTPM, at the same time pursuing the objectives of the PVSS.TSI project. For more information about the two projects, please refer to [WWW-STMO].

1.3 Objectives

The goal of the project is the development of a *software application* for the CERN Technical Control Room (TCR) and the Prévessin Experiment Control Room (PCR). This software application shall allow the control rooms' operators to remotely monitor the start-up of the Super Proton Synchrotron (SPS) after major breakdowns.

The application shall be based on PVSS and its user interface shall consist of a series of mimic diagrams, so-called PVSS panels, that display the current status of all systems involved in the accelerator's start-up, i.e. electricity, demineralised water, vacuum and other systems.

From a central view, consisting of some boxes displaying the system states on a very high level (one box per system), the operators shall be able to get more detailed information by clicking on the boxes and zooming in to the systems concerned. The user interface shall allow the operators to localise defects, the cause of the defect will then be detected using existing tools.

In order to implement such an application, it is necessary to *set up a SCADA system* that acquires data from existing equipment control systems, notably the Technical Data Server (TDS) and SL-Equip. PVSS II was chosen to fulfil this task. The PVSS system shall be configured in a redundant way in order to increase the system's dependability. Furthermore, data exchange with other PVSS systems at CERN shall be possible. In order to acquire data from the control systems mentioned above, the implementation of a *PVSS driver to SL-Equip* is necessary. A driver to the TDS already exists and can be reused.

Finally, the PVSS system has to be configured in order to acquire data using the drivers mentioned above. The configuration information required for this purpose is currently stored in:

- the Technical Data Reference Database (TDRefDB),
- formatted ASCII text files and
- paper files.

This configuration data shall first be converted into a homogenous format (introduced in a database) and then injected to the PVSS system at run-time.

1.4 Project Proceeding

This chapter deals with the project engineering aspects of the system development process. The development approach chosen is described as well as important project milestones (anchor points).

1.4.1 Project Development Model

As the SPS Restart Application was the first PVSS application developed within the ST/MO group, little experience on this subject was available. Consequently, a complete specification of the project was difficult to establish from scratch and several iterations were necessary to capture all user requirements. Initially, only four project anchor points were defined:

(1) the set-up and configuration of the PVSS system,
(2) the implementation of the PVSS driver to SL-Equip,
(3) the development of a data loader and
(4) the development of the application's user interface.

These four anchor points were treated as interdependent subprojects; each of them was dealt with using an evolutionary prototyping approach. Prototyping means building a small version of a system, usually with limited functionality, that can be used to help the user or customer identify the key requirements of a system and demonstrate the feasibility of a design or approach" ([Pfleeger, 1998]).

As opposed to a throw-away prototype that is not intended to be used as an actual part of the delivered software, an evolutionary prototype is "*developed to learn about a problem and form the basis for some or all of the delivered software*" ([Pfleeger, 1998]).

Accordingly, as soon as a basic set of requirements was defined, a first prototype was built and presented to the potential users. Based on their feedback, the requirements were refined and further functionality was integrated in the prototype until a satisfactory solution was found.

1.5 Overview of the Document

This document contains the description of the SPS Restart Monitoring Application, which has been developed and implemented for the Technical Control Room (TCR) at CERN in order to provide an appropriate tool for monitoring the status of all systems involved during the start-up of the Super Proton Synchrotron.

The notation of this work is kept very simple. While textual descriptions and explanations of mechanisms and functions are written in a serif font (Times New Roman), any source code extracts as well as class, method and variable names etc. are written in `fixed-pitch` font (`Courier New`). Important names, key terms and central messages of a chapter are emphasised using an *italic* font.

Chapter 2 gives an overview of the technologies and techniques used in the course of the SPS Restart Application project. It serves as an introduction for readers who are not familiar with

SCADA systems in general and with PVSS II in particular. Furthermore, SL-Equip, an equipment control middleware implemented and used at CERN, is presented. Last but not least, a presentation of the SPS, CERN's second largest accelerator is given.

Chapter 3 provides an extensive description of the problem that triggered the launch of the SPS Restart Application project. After an outline of the general problem, the subtasks to be solved by the author are dealt with in detail.

Chapter 4 describes the proposed solution, particularly focusing on the system's design. The chapter follows the same structure as chapter 3, starting with an overview of the designed system and then dealing with its components one by one.

Chapter 5 describes the implementation of the system, explaining the major concepts used as well as some interesting implementation details. Special emphasis will be put on the implementation of the PVSS driver to SL-Equip and the off-line PVSS configuration database.

Chapter 6 deals with validation and verification aspects and describes how the SPS Restart Application was tested.

Chapter 7 contains a concise summary of the thesis and gives a brief overview of unsolved problems, possible extensions and potential weaknesses of the implemented solution.

2. BASIC NOTIONS

This chapter introduces the reader to the most important concepts and tools used in the course of the project. First, a brief introduction to the concept of SCADA systems is provided, followed by a presentation of PVSS II as an example of an industry SCADA system. Finally, SL-Equip, the middleware that will provide equipment data for the SPS Restart application, is introduced

2.1 Supervisory Control and Data Acquisition Systems

As this work is mainly concerned with SCADA systems, an introduction to this technology is crucial for readers who are not yet familiar with it.

2.1.1 Definition of SCADA-Related Terms

First of all, we will define the term *Supervisory Control and Data Acquisition* (SCADA) according to our needs and try to point out the differences to similar concepts. Two of the most important characteristics of SCADA systems are already included in the acronym:

(1) the capability to *collect data* from some kind of installation and
(2) the ability to *control* these facilities sending (limited) control instructions.

What is not mentioned, however, is that

(3) SCADA systems are typically used to supervise and control facilities in *remote locations*.

Putting these three elements together, we define that SCADA is a "technology to collect data from one ore more distant facilities and/or send limited control instructions to those facilities" [Boyer, 1999].

Although SCADA systems limit the amount of control that can be exercised, they still do allow (supervisory) control. This is one of the points that distinguish SCADA from similar concepts, such as telemetry: SCADA systems are *two-way systems*, allowing not only to monitor what is going on at a remote location but also to do something about it.

As this thesis is exclusively concerned with the software aspects of SCADA technology, we will refine our definition and describe SCADA systems as "*commercial software systems used extensively in industry for the supervision and control of industrial processes*" [WWW-IT/CO]. In this interpretation, a SCADA system is regarded as a *purely software package* that is positioned on top of the hardware to which it is interfaced.

[Daneels and Salter, 2000] stress that "*SCADA systems are used not only in industrial processes […] but also in some experimental facilities*". This fact is worth pointing out, as an industrial SCADA system will be used for the development of the controls of the four LHC experiments at CERN. Besides, the purpose that we want to use a SCADA system for in the course of the SPS Restart Application project cannot be classified as a typical industrial process.

2.1.2 General Architecture of SCADA Systems

Now that we have a basic idea of what SCADA systems are and what they are used for, we will examine some architectural aspects that are common to virtually all products available on the market. We do not want to lose ourselves in technical details but will understand the functioning of a SCADA system from a (software) engineer's point of view.

For SCADA technology is utilised to monitor and control remote facilities, the system must inevitably be divided in *local and remote components* that exchange information via some kind of communication medium. In software terms, we could call it a layered architecture, consisting of a *client layer* with a human machine interface and a *data layer* (referred to as "data server layer" in [Daneels and Salter, 2000]), communicating with devices in the field. Ideally, these two layers are complemented by an intermediate layer, doing computations on the data received, filtering information, etc. We will refer to this third layer as *processing layer* and consider it equivalent to the business layer in traditional three-tier software architectures.

[Boyer, 1999] describes a similar system structure, decomposing a generic SCADA system into an operator interface, a Master Terminal Unit (MTU) and a series of Remote Terminal Units (RTU) communicating with the equipment in the field.

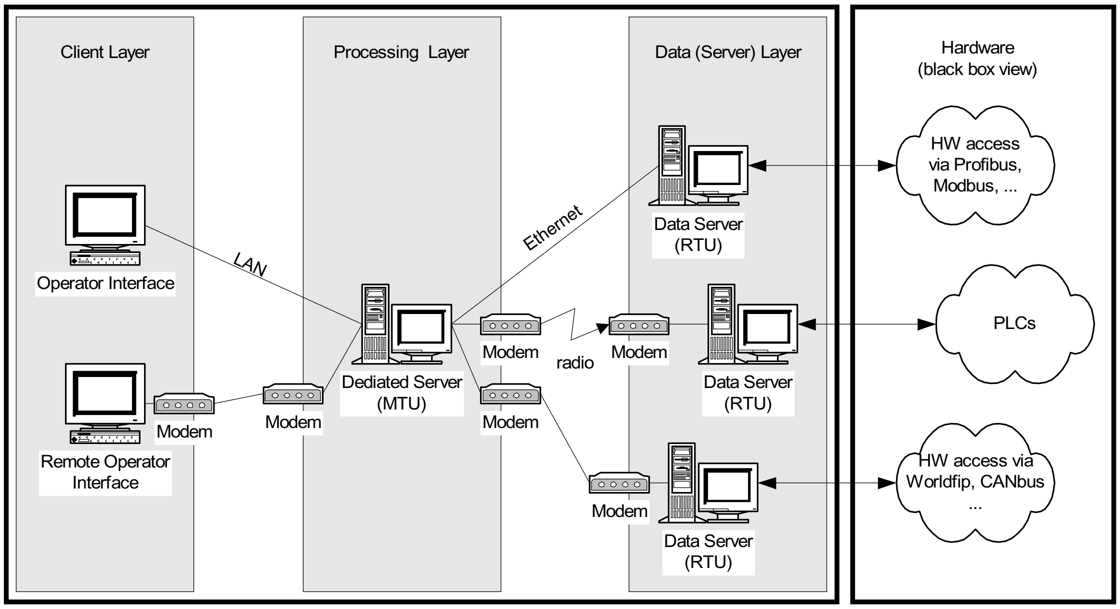


Figure 2-1 Example of a generic SCADA system (architecture)

Figure 2-1 shows an example of such a generic SCADA system. Although it does not cover all possible system architectures, especially all imaginable means of communication, it illustrates the following aspects:

- the separation of client, processing and data layer.
- the distinction between SCADA components and the equipment controlled.
- the different means of communication used for data exchange between client and processing layer, between processing and data layer and, finally, between data layer and the hardware.

After this overview of the physical distribution of the software components, we will elucidate the tasks fulfilled by each of the layers.

2.1.2.1 Client Layer

In the centre of a SCADA system are its operators who are accessing the system by means of a *human machine interface (HMI)*, known in other parlance as an *operator console* or *user interface.* This HMI consists of a video display unit (VDU) that displays real-time data about the supervised process and of an input device for sending control instructions. What kinds of VDU and input device are used depends largely on the complexity of the supervised system. In the case of very simple systems, a computer screen and some electrical switches would suffice even though today's PC-based SCADA systems almost exclusively use colour screens for displaying data and often include audible signals to attract the operators' attention in case of emergency. Keyboard and mouse or touch screens are used for inputting the operators' commands or messages back to the process.

The following list gives an overview of functionality implemented in the client layer without claiming to be complete.

- Combinations of synoptic diagrams, text and elements for navigation are displayed on multiple screens.
- Graphical objects and user interface elements can be linked to process variables in order to display/reflect their value at run-time.
- Configuration panels and/or tools allow privileged users to modify the system's set-up at run-time, to add/remove process variables and to customise the HMI.
- Trending charts visualise the evolution of certain process variables over time. Trending can be done with on-line data as well as with historical information stored in the system's database.
- Alarm screens inform operators about pending alerts (e.g. if the value of a process variable or expression leaves it pre-defined good-range)

To sum up, we can say that the client layer's main task is to display/visualise information it receives from the processing layer and to interact with the user.

2.1.2.2 Processing Layer

Having said the above, it is clear that the HMI directly interfaces with a master terminal unit (MTU). The advantages of having an MTU that acts as a system controller and hence as a mediator between the operator interface and the RTUs can be summarised as follows:

- A series of tasks can be executed automatically and do not need any operator interaction. They can even be performed during the operator's absence by means of a built-in *scheduler* that repeats pre-programmed actions at set intervals.
- A special *alert behaviour* can be triggered whenever a process variable passes a pre-defined threshold. The system can react by performing an emergency shut down, notifying the operators via an alert screen or other communication systems such as GSM phones or pagers.
- As all process variables are managed by the MTU that all clients connect to, all clients see the same values at the same time. If clients connected directly to the data servers, synchronising the HMIs would be a much more difficult task.

- Complex computations, e. g. statistical functions, can be performed at the MTU-level. This avoids that all clients have to do the same computation, which would be a waste of computing power, especially if the clients are installed on average workstation machines.

The core feature of the MTU is certainly that it *collects data from the data servers and then distributes it to its clients*, usually in an event-driven way. In this way, any piece of information is transmitted from the remote location only once, which is crucial if remote facilities are connected to the local components via a low-bandwidth communication medium.

2.1.2.3 Data (Server) Layer

The data server layer builds the final link to the hardware in a SCADA's data acquisition chain. It consists of one ore more data servers (called RTUs in Boyer's terminology) that are directly connected to one or more MTUs via various communication media. As the data servers are usually remote from the MTUs, long-distance communication media, such as radio, telephone lines, fibre optic cables etc., are used for this purpose. All the same, RTU and MTU can equally be connected via a LAN or, in exceptional cases, be installed on the same machine, which will be the case at CERN.

The key task of a data server is data acquisition. The servers are connected to hardware equipment, programmable logic controllers (PLCs) or, exceptionally, to other data acquisition systems via a variety of protocols. Usually, field buses (e.g. Profibus, Modbus, Bitbus, CANbus etc.) are used for communication.

In most cases, data is acquired from the hardware via a *polling mechanism*. In electronic communication, "polling" is the continuous interrogation of other programs or devices by one program or device to see what state they are in, usually to see whether they are still connected or want to communicate [WWW-WHATIS]. This implies that it is up to the data server to detect value changes and to forward these changes to the MTU as needed.

2.1.3 Features of SCADA Systems

At this stage, the reader is familiar with basic SCADA-related terms and knows how a typical SCADA system is structured. The following section will draw attention to the features and functions that modern SCADA products should include.

[WWW-ITCO] and [NFESC, 1991] identify the following features:

- Data acquisition with a very high data throughput (up to several thousand values per second)
- Ready-to-use drivers supporting standard communication protocols (e. g. field bus protocols, OPC etc.)
- Extensive processing power that is often distributed on several computers.
- Extremely short response times.
- Off-line processing.
- Automatic control mechanisms that do not require the operators to be present all the time (e. g. scheduled tasks, emergency actions etc.)
- Alarm handling (i. e. reacting to values passing certain thresholds)
- Data logging and archiving as well as the possibility to manipulate historical data.

- Access control mechanisms (e. g. an authorisation mechanism based on a user/group concept)
- User-friendly HMIs including many standard features (e.g. alarm display, trending etc.) and often based on graphical operating systems

It goes without saying that this list is not complete. Even so, it gives a good overview and can serve as a starting point when evaluating and comparing different products available on the market.

2.1.4 Benefits From the Use of SCADA

As it was mentioned before, the basic idea behind SCADA systems, as behind any remote control mechanism, is to make it unnecessary for operators to be assigned to stay at or frequently visit remote locations when those remote facilities are operating normally. From a control system's perspective, the advantages of SCADA technology are obvious:

- Process data for monitoring is centralised.
- Process equipment can be operated remotely.
- The number of site visits required to remote stations is reduced (which leads to a reduction of man-hours in operation).

All the same, we also want to draw attention to the benefits from the use of industrial SCADA systems, which are usually commercial off-the-shelf (COTS) products, from an economic point of view:

- The effort invested in the development of an industrial SCADA system amounts to 50/100 person years. Re-implementing all this functionality could be compared to re-inventing the wheel.
- The amount of specific development that needs to be performed by the end-user is limited.
- Technical support and maintenance are provided by the vendor.

In spite of these facts, SCADA technology is not applicable everywhere. The ensuing section will therefore show the limitations of SCADA technology.

2.1.5 Limitations of SCADA Technology

Although there are hundreds of application areas for which SCADA technology is excellently suited, some process control and data acquisition functionality should not be handled remotely. [Boyer, 1999] cites two types of systems that should in no case depend on SCADA: (1) product measurement systems that are used for billing or paying taxes and are thus required to keep an audit trail and (2) safety-instrumented systems. In the first case, the reason is very simple: systems used for the calculation of taxes are subject to government regulations and require a paper trail allowing auditors to check whether proper accounting has been made. The case of safety-instrumented systems is more interesting. The failure of a safety-instrumented system may result in the injury or death of a person or cause damage to equipment or the environment. Consequently, safety-instrumented systems must meet certain design criteria that considerably increase the system's complexity.

It is also worth pointing out that SCADA systems can only reduce the number of site visits as long as the *remote facilities are operating normally*. If the remote system fails or does not respond any more, the maintenance team still has to go on site.

2.1.6 Outlook to the Future

The current trend in SCADA industry is the migration to completely open systems, the ambition to build "*open architectures, allowing RTUs to be interchanged between systems from different vendors*" [NFESC, 1991]. It goes without saying that this goal is not new and not at all limited to SCADA technology. The whole software industry is working on open system solutions (e.g. markets for interchangeable components supporting standard interfaces) but, unfortunately, these noble intentions are often counteracted by economic considerations.

All the same, modern SCADA systems are usually designed to be extensible to a certain degree. PVSS II, for example – the SCADA system we are going to take a closer look at in the next chapter – permits the implementation of flexible control scripts and the development of additional modules using the same API the vendor used for implementing the system itself.

2.2 PVSS II – An Example of an Industry SCADA System

PVSS II, the abbreviation of "*ProzeßVisualisierungs- und SteuerungsSystem*"[1], is an industrial SCADA product developed by ETM, an Austrian company with its headquarters in Eisenstadt, Burgenland. The main reasons why we will take a closer look at this product are the following:

- After a three-year selection process, PVSS II has been selected as the CERN recommended SCADA system for all LHC experiments.
- PVSS II is currently being evaluated as the standard SCADA system for the whole of CERN.
- PVSS II forms the core of the SPS Restart Monitoring Application described in this work. Its concepts should thus be well known to the reader.

This chapter introduces PVSS. It is necessary to explain the architecture of a PVSS system and the basic concepts used, in order to understand how the problem was solved.

2.2.1 Product Description

According to [ETM, 2000], PVSS II is an "object-oriented process visualisation and control system [that] allows you to implement solutions tailored to specific customers".

The vendor describes his product as follows:

> "PVSS is an industry-neutral, universally implementable process-control system that can be used to help visualise, monitor and control technical sequences. It works across multiple computer platforms, is multilingual and has a modern, totally graphic User Interface." [ETM, 2000].

[1] process visualisation and control system

The author's experience with the product has shown that the citation above is correct – at least as far as the qualities listed in the second sentence are concerned. This does not mean that PVSS is perfect but it provides a range of features that make it superior to comparable products on the marked.

[WWW-ITCO] summarises the following strengths of PVSS that make it interesting in the HEP domain:

- It can run in a distributed manner with any of its processes running in a distributed manner.
- It is possible to integrate distributed systems.
- It has multi-platform support (Linux, Microsoft Windows NT 4.0 and Microsoft Windows 2000)
- It is device oriented with a flexible data point concept.
- It has advanced scripting capabilities.
- It has a flexible API allowing access to all features of PVSS from an external application.

2.2.2 The Data Point Concept

PVSS II is based on various concepts. The central element that is found in all areas is its flexible *data point concept*. External and internal variables, user authorisations, the activation of system images or alarms – all these things make use of so-called data points.

Before we go into details, we will define a couple of terms that will be helpful for the understanding of this thesis: A *data point type (DPT)* defines a named data structure and consists of one or several typed *data point elements (DPE)*. DPEs can themselves be structures and thus have subordinated elements. The term *data point* (DP) designates a named instance of a DPT. Finally, so-called *configs* can be associated with DPEs and DPs. Configs are pre-defined sets of configuration information that are used for multiple purposes, e. g. for associating DPEs with concrete process variables, for archiving, for the calculation of statistical values etc.

In many conventional SCADA systems, the organization of data is fixed and very inflexible. Each process variable (i. e. each value acquired from the hardware and each internal variable) is mapped to an individual data point, which means that complex systems are divided into huge amounts of unstructured data points that are difficult to manage. ETM's intention was to create a data point concept that is oriented at the real structure of the data being processed and thus "object-oriented". Indeed, PVSS allows the definition of data point types (DPTs) that consist of several data point elements (DPEs) and are similar to structs in C or records in PASCAL. All the same, they have nothing to do with object-oriented classes in software technology, for they only define the structure of the data but do not include operations. If the vendor claims that the DP concept is object-oriented, this is only true if we reduce object-orientation to the possibility of creating structured data types that do not support inheritance, dynamic binding and polymorphism.

2.2.3 PVSS System Architecture – The Manager Concept

To get a better understanding of how PVSS works, the present section gives a brief overview of the PVSS system architecture and introduces the reader to the PVSS II Manager concept.

In PVSS terminology, a manager is a process (known in other parlance as a task). The manufacturer supplies several managers, each assuming a certain role in the system (e. g. data acquisition, archiving, data processing, etc.). Additional managers can be developed by the user – as a system extension – by means of the PVSS API.

Basically, PVSS II implements a client-server architecture with the event manager (EM) acting as a server for all other managers. The manufacturer presents his system as divided into four layers that are depicted in Figure 2-2: (1) the user interface layer, (2) the processing layer, (3) the communication and storage layer and (4) the driver layer. As we want to map this schema to the three-tier architecture described in 2.1.2, we will simply group (2) and (3) together.

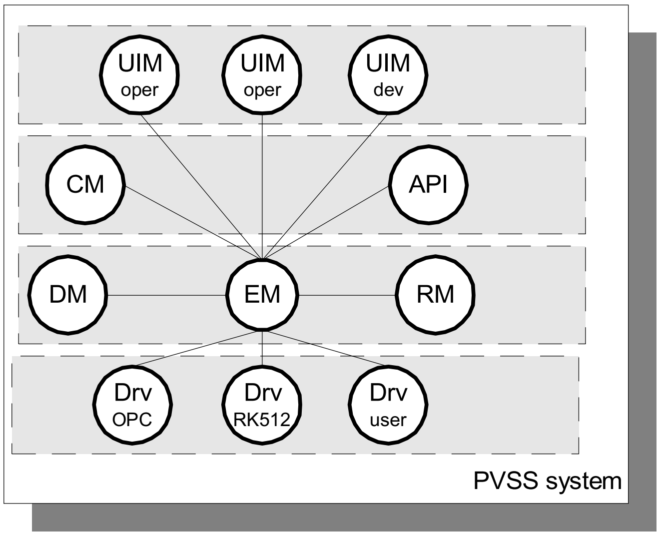


Figure 2-2 General PVSS system architecture

We now take a look at the different standard managers and at the functionality they provide.

2.2.3.1 Event Manager (EM)

As it was mentioned above, the event manager is the central part of a PVSS system; receiving messages, evaluating and distributing them to other managers. It acts as a kind of co-ordinator that all other managers connect to. Due to this, each PVSS system can only have *one* event manager, with the exception of a redundant system.

2.2.3.2 Database Manager (DM)

In collaboration with the event manager, the PVSS database manager is responsible for

(1) keeping a copy of the current process image (i. e. the current values of all data points) in memory and
(2) archiving value changes in a high-speed database.

As there can only be *one* copy of the current process image, there can only be one database manager per system, again, with the exception of a redundant PVSS system.

The archiving mechanism used by PVSS is very flexible. As all internal and external values (process variables, internal variables and configuration information) are stored in a database, all of them can be treated analogously. Individual value archives are used for different groups of data points (e. g. for different parts of the monitored system) and it is up to the user to decide whether a value should be archived or not. All the value archives run as separate processes and their activity is co-ordinated by the Database Manager.

2.2.3.3 Control Manager (CM)

As mentioned in 2.1.6, PVSS was designed to be very open and extensible. A special programming language called *Control* was integrated in the system to keep it "*flexible and universal*" [ETM, 2001]. Control is ANSI-C compatible and for that reason easy to learn for confirmed programmers. It is utilised throughout all PVSS II modules for:

- linking user components to DPEs,
- creating complex control functions,
- testing and simulation tasks,
- batch configuration of data points,
- automatic execution of complex calculations,
- etc.

One more argument for the use of Control is that it has already been used for the creation of standard components delivered with PVSS and is thus well tested by the vendor.

Control managers are used for loading custom or standard script libraries into memory and hence for making library functions accessible to other managers. Functions can be linked to DPEs via a special config or also to user interface components and are then executed in an event-driven way. Control offers language constructs for multi-threading and so Control managers can concurrently process several functional blocks.

2.2.3.4 Driver Managers (Drv).

Driver managers establish the *communication link between PVSS and the hardware to be supervised/controlled*. They are thus equivalent to the data servers in the generic SCADA architecture described in 2.1.2.

On the one hand, drivers for the most widely used protocols are delivered with the product (Muehbus, OPC, pager, Profibus, RK512, SSI and a simulator). On the other hand, the PVSS API also offers the possibility to implement further driver managers supporting proprietary communication protocols or recent developments. As the development of a PVSS driver is a major concern of this work, we will come back to PVSS drivers later on.

2.2.3.5 User Interface Manager (UIM)

The User Interface Manager is the PVSS implementation of the generic client layer described in 2.1.2.1. So-called PVSS panels are used for the visualisation of process status information and for forwarding user input to the event manager. Such panels are created using a graphical editor and then saved as ASCII files, which makes them portable between UNIX and Microsoft Windows platforms.

Panels can contain Control scripts for linking user interface components to DPE values. The graphical editor considerably facilitates the creation of such scripts and several wizards generate scripts for implementing standard functionality (e. g. displaying the value of a DPE in a text field, changing the background colour of a UI element etc.).

2.2.3.6 Other Managers

The aforementioned managers can be found in virtually all PVSS systems. Some other, more specialised managers are also supplied and used as needed, e. g. the redundancy manager, the distribution manager or the ASCII manager. The ASCII Manager allows the export of PVSS configuration data (DPTs, DPEs configs etc.) from the internal high-speed database to specially formatted ASCII files and also the import of configuration information from such ASCII files.

2.2.4 Scattered and Distributed PVSS Systems

These two terms are slightly confusing, as they have a similar meaning in English but are interpreted differently in PVSS terminology. A *scattered* PVSS system is defined as one PVSS system with its managers distributed on several machines, whereas the term "*distributed systems*" designates an ensemble of independent PVSS systems that are linked via a network to mutually access their data points. This section provides explanations and examples of use cases for both system types. Anticipating that both concepts will be used in the course of the SPS Restart project, their understanding is essential.

2.2.4.1 Scattered Systems

One of the main advantages of PVSS over other commercial SCADA systems is the option to distribute the PVSS managers forming a system on different machines in a network. As the managers communicate via TCP/IP sockets, there are no restrictions concerning the operating systems on which the managers run (with the exception that PVSS must be available for the operating systems in question). A use case will illustrate the advantages of the scattered system concept.

Use case for a scattered system. Following a series of performance tests that have shown that the UNIX implementation of PVSS is more efficient than the Windows version, it has been decided to run the core system (consisting of EM, DM, CM and a driver) on a Linux server. Even so, TCR operators feel more comfortable with the Windows look-and-feel and want to take advantage of the possibility to integrate ActiveX components in their PVSS panels.

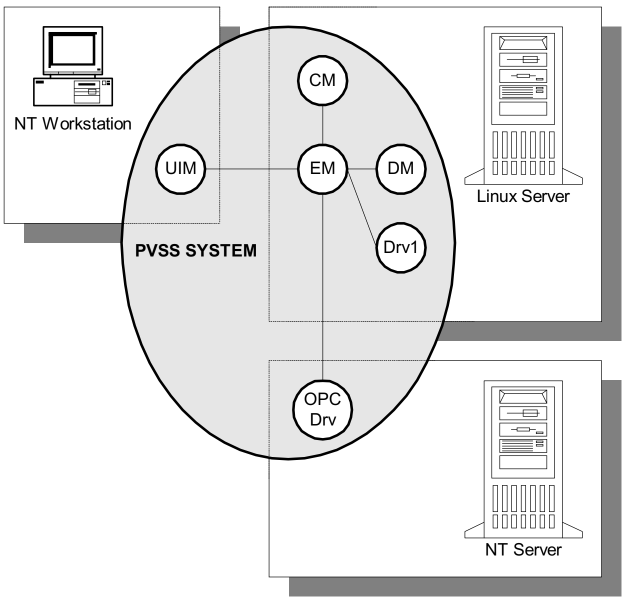


Figure 2-3 Example of a scattered PVSS system

After the initial installation, new hardware, controlled by a driver using OLE for Process Control (OPC), is added to the system. As OPC is based on Microsoft's OLE/COM technology, it is not available for Linux. The core system can still run on UNIX and only the driver will be running on a Microsoft Windows NT 4.0 server. The structure of the resulting system is depicted in Figure 2-3.

2.2.4.2 Distributed Systems

As explained above, distributed systems allow different PVSS systems to communicate with each other and to exchange data. This feature is very useful in large organizations, such as CERN, where several organizational units are responsible for data acquisition but also want to share their data with others.

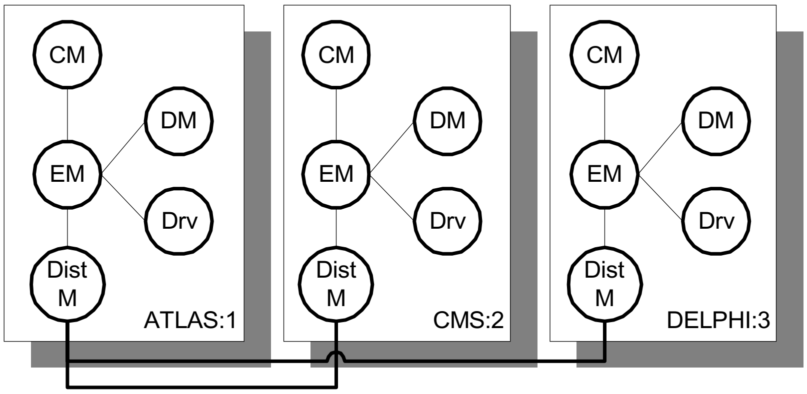


Figure 2-4 Example of a distributed PVSS system

Distributed PVSS systems are linked via a separate *distribution manager* (DistM) that keeps the linking of the systems as transparent to other PVSS managers as possible. A distribution manager is able to maintain the logical connection to several distribution managers of other PVSS systems over different networks. The drawback of the current PVSS distribution concept is that all participating systems must know all other systems by their system id and their hostname (i.e. the host name of the machine running the event manager). Adding a new system therefore requires a lot of effort that could be saved if an intelligent naming service was used.

An (imaginary) example of a distributed PVSS system is illustrated in Figure 2-4. In this case, system LHC can access the data points of CMS and DELPHI (two LHC experiments). CMS and DELPHI, however, do not know each other and can only read data points provided by LHC.

2.2.5 The PVSS Redundancy Concept

If SCADA technology is used to supervise and control a large number of mission-critical components, it is vital to design the system for high *dependability*. One of the approaches to increase the dependability of a system is the introduction of redundant components that back up primary resources in case of failure. The option of having a redundant system is an integral part of PVSS II and is implemented as illustrated in Figure 2-5.

The same set of managers (EM, DM, CM, drivers etc.) is running on both systems, so that each of them is able to operate independently of the other. Additionally, a special *Redundancy*

Manager (RM) is installed, with the task of co-ordinating the two systems, so that only one of them is active at a certain point in time. Ideally, the redundant systems should also dispose of a redundant network connection, where one is used for the exchange of data (*synchronisation*) and the other one is used for the exchange of status information.

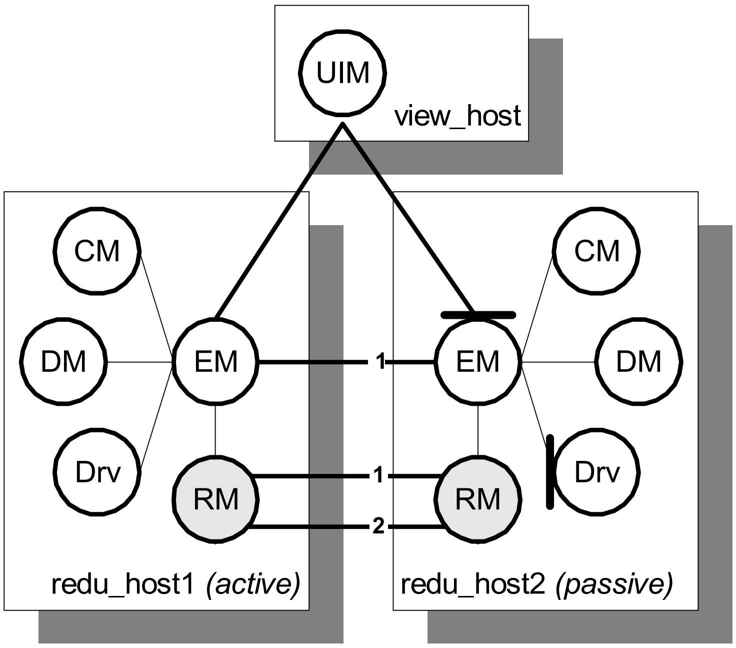


Figure 2-5 Architecture of a redundant PVSS system

A *user of a redundant system* (UIM) always connects to both redundant hosts and all requests are forwarded to both event managers. All the same, the *passive system* (redu_host2 in Figure 2-5) blocks the client calls. The active system processes the requests and then forwards the results to the passive system. This mechanism that is equally used on the hardware side, avoids inconsistencies between the two systems.

2.3 The SL-Equip Package

SL-Equip represents a set of equipment access routines that "offer a flexible and generic interface to heterogeneous equipment, such as 1553, GPIB, BITBUS, RS232, as well as to specific user software, such as industrial PLCs or SPS data modules" ([Charrue, 1993]). This package will be used for the implementation of a PVSS driver; we will therefore try to understand its underlying concepts.

The idea of the SL-Equip package – SL-Equip stands for SPS-LEP Equipment – is to *exchange data* with heterogeneous remote devices located all around the two accelerators. The client side, which we are mainly interested in, consists of a set of equipment access routines written in C.

2.3.1 System Architecture

Without going into details, this section gives a concise overview of how equipment access via SL-Equip works and describes all the libraries and processes involved.

Seen from a process-oriented point of view, SL-Equip is divided into four components:

(1) the application program on the client-side,
(2) the SL-Equip Message Handler,
(3) the SL-Equip Equipment Name Server and
(4) one or several Equipment Servers.

Three library packages are used in order to make the communication between these components transparent for the user:

(1) the client API,
(2) the Equipment Server API and
(3) the supported equipment libraries.

Figure 2-6 illustrates the interaction between the components enumerated above as well as the means of communication used.

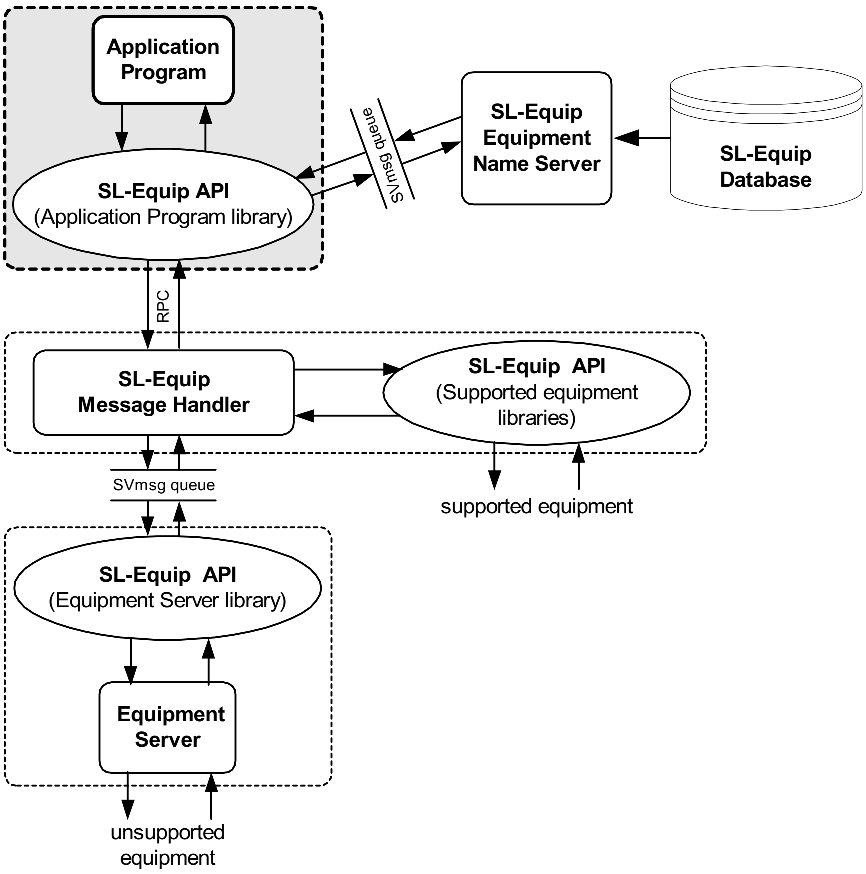


Figure 2-6 SL-Equip system architecture

The *application program* is a piece of software that makes data exchange with a piece of equipment by means of functions provided by the SL-Equip API. It forms the client side of

SL-Equip and can be written in C/C++ or NODAL[2]. The PVSS driver to be developed in the course of this project will be such an application program.

The *SL-Equip Name Server* is a UNIX background process that handles the Equipment Database containing all information that is needed by the client API in order to communicate with the equipment.

The *SL-Equip Message Handler*, like the Name Server, is a UNIX background process that receives Equipment Messages sent from application programs and routes them according to their types. It allows direct access to supported equipment as well as Equipment Server access. It forwards the Equipment Message, waits for an answer and returns this answer to the application program.

When talking about *equipment* in the context of SL-Equip, we mean *a piece of hardware that is accessed by the application program*. Several types of equipment are supported (1553, MPX, CAMC, GPIB and BITBUS) and can be directly accessed from the Message Handler. Other types of equipment must be accessed via special Equipment Servers.

An *Equipment Server* is a piece of software written by the user in order to directly control equipment that is not supported or when there are complex actions to be performed on the equipment. Equipment Servers are written in C and process messages forwarded by the SL-Equip package.

2.3.2 Equipment Naming Conventions

Every piece of equipment that shall be accessed through the SL-EQUIP package is referenced by a logical name that can have one of two formats:

(a) it is made with two 6-byte strings called *family* and *member* or
(b) it consist of a 64 bytes string.

We will always use form (a), as (b) is not supported by all equipment.

In addition to family and member, a so-called *action* designates a specific part of the equipment accessed. Like family and member, the action consists of a 6-byte string and is a mandatory part of each SL-Equip client call. A *user option* allows some extra data to be sent, especially when the transaction is a read and the user needs to specify which data needs to be read from the equipment. Finally, a so-called *mode* specifies the type of data exchanged and its direction. The modes that are currently supported by the package are listed in Table 2-1. Modes starting with ‘R’ are used for read access, those starting with ‘W’ for write access and those starting with ‘X’ for bi-directional access.

Mode	Explanation
RBR, WBR, XBI	Read/write 32-bit floating-point numbers
RAR, WAR	Read/write 32-bit floating-point numbers. The data will be converted to an ASCII string before being transmitted.
RS, WS	Read/write ASCII strings (array of 8-bit characters)

[2] NODAL is an interpreted language used by CERN and DESY, a high-energy physics centre in Hamburg, Germany, to control their accelerator hardware. [WWW-HEUSE]

Mode	Explanation
RBI, WBI	Read/write short integers (16-bit)
RAI, WAI	Read/write short integers (16-bit). The data will be converted to an ASCII string before being transmitted
RB, WB, XB	Read/write binary (8-bit) data

Table 2-1 Definition of SL-Equip modes

2.3.3 SL-Equip Client Calls

Having explained how SL-Equip components interact, we describe the three steps that need to be performed by the application program to access equipment data:

(1) Resolve the equipment name.
(2) Pack the data in a network format and call the equipment server concerned.
(3) Receive the returned call, unpack the data and return a status to the calling program.

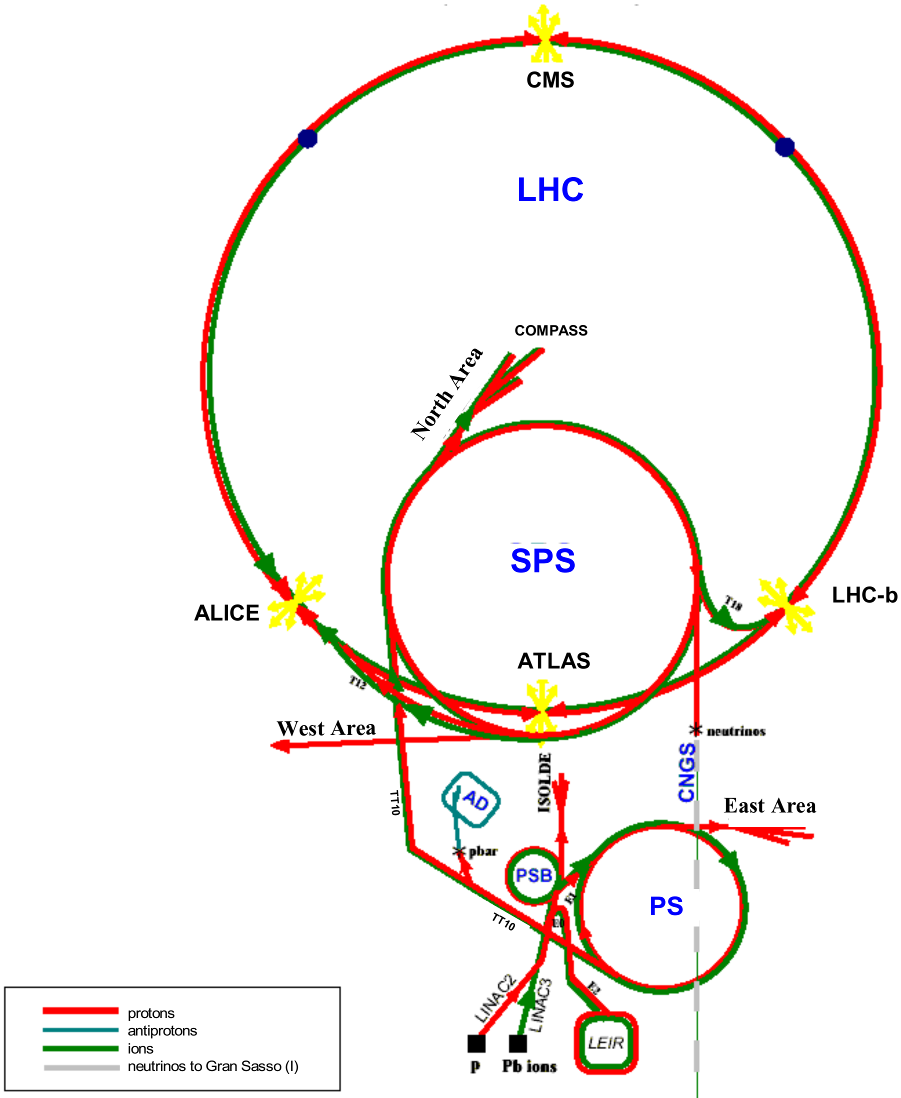
These three steps will be essential for developing the PVSS driver to SL-Equip.

2.4 The Super Proton Synchrotron

As the goal of this work is to develop an application for monitoring the start-up of the *Super Proton Synchrotron (SPS)*, this section provides the reader with some background information about CERN's second largest accelerator.

The SPS is a circular particle accelerator, about seven kilometres in circumference and buried 50 metres under the ground. The SPS ring consists of six 1024 metre long curved sections (the so-called *sextants* BA1 to BA6) that are interconnected by 128-metre straight sections. It was originally built in 1976 to accelerate protons – and still does so – but it has since operated as a proton-antiproton collider, a heavy-ion accelerator, and an electron/positron injector for LEP. As a proton-antiproton collider in the 1980s, it provided CERN with one of its greatest moments - the first observations of the W and Z particles, the carriers of the weak force [WWW-CERN]. The SPS can also accelerate lead ions to an energy of 170 GeV per nucleon, with 208 nucleons in the lead nucleus. At present, this is the highest energy obtained in the world, and it serves the study of the quark-gluon plasma which may have occurred shortly after the big bang.

As can be seen in Figure 2-7, the SPS continues to provide beams for the LEP/LHC machines and forms the backbone of CERN's accelerator complex. Particles coming from the Proton Synchrotron (PS) are injected to the SPS tunnel via transfer tunnel 10 (TT10).



LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Protron Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

Figure 2-7 The CERN accelerator complex

3. PROBLEM DESCRIPTION

This chapter presents an exhaustive description of the problem to be solved in the course of this thesis work. To start with, the general problem of an application monitoring the start-up of the SPS is presented and then, the overall task is broken down to subtasks to be solved by the author himself. These subtasks are specified in detail.

3.1 Overview of the Problem

The project's main objective is the development of a software application that facilitates the monitoring of all SPS subsystems involved in the accelerator's restart after major breakdowns. In particular, the supervision of electrical installations, the vacuum system and the raw and demineralised water circuits are concerned. The application based on a PVSS SCADA system shall provide an easy-to-use interface to monitor the subsystems of the SPS involved in the start-up procedure.

3.2 Parts of the Problem – Scope of the Project

This section focuses on the parts of the problem to be solved by the author that are presented in this work. The task of developing a PVSS application for monitoring the SPS restart is broken down to the following subtasks:

(1) the set-up and configuration of the PVSS system serving as a basis for the application,
(2) the development of a PVSS driver to acquire data from the SL-Equip middleware,
(3) the implementation of a data loader for importing the static PVSS configuration (DPTs, DPs, configs etc.) from an off-line database and
(4) the design of some mimic diagrams for the application's user interface.

3.2.1 Set-up and Configuration of the PVSS System

As PVSS will be used as the core of the SPS Restart Application, the set-up and configuration of the system in accordance with the functional requirements and constraints presented in this section plays an essential role for the success of the project.

3.2.1.1 Design for High Dependability

Dependability is "*that property of a computer system such that reliance can justifiably be placed on the service it delivers*" [Barbacci, 1995]. Software dependability includes a range of characteristics, such as reliability, security and safety.

High dependability is required because the SPS Restart Application shall be used in two of CERN's main control rooms, available 24 hours a day, 365 days a year without interruption. The system design has to reflect this requirement.

3.2.1.2 Design for Data Exchange

As all data that is acquired from an equipment has to be transmitted via a dedicated control network, it would be a waste of bandwidth to acquire the same information twice for different PVSS projects. As a consequence, a *mechanism for sharing the data acquired with other PVSS systems* shall be provided.

3.2.1.3 Implementation Constraints

Tests carried out at CERN in order to evaluate the performance of several SCADA products under consideration for the LHC experiments have shown that the Linux implementation of PVSS II can handle twice as many value changes per second as its Windows (NT/2000) version (see [WWW-ITCO]). Seeing that the number of value changes per second is crucial for the performance of a SCADA system, it was decided to install the *core PVSS system* for the SPS Restart Application *on a Linux platform*. Like for all Linux Systems at CERN, a Redhat Linux 6.1 distribution adapted to CERN's specific needs has to be used.

Nonetheless, as the Windows version of the PVSS user interface is more intuitive to use and also allows the integration of ActiveX components, it was decided to run the *PVSS front-end*, i. e. the mimic diagrams for the SPS Restart Application, *on Windows 2000 workstations*. For more details concerning the mimic diagrams, please refer to section 3.2.4.

3.2.2 Implementation of a PVSS Driver to SL-Equip

Since all electrical equipment involved in the start-up of the SPS is currently monitored and controlled by SL-Equip, a driver to this middleware has to be developed. Bi-directional equipment access, i. e. reading out data provided by the equipment and sending command instructions to the hardware, shall be supported for integer, floating-point and string values. Furthermore, a mechanism to propagate SL-Equip error codes to the PVSS application shall be provided.

As both, the PVSS API and the SL-Equip client-side library, are implemented in C/C++, the same programming language shall be used for the implementation of the driver. Seeing that the core PVSS system shall run on Linux (see chapter 3.2.1.3) and the SL-Equip libraries are not available for Windows, the driver will be developed for a Linux platform.

3.2.3 Implementation of a Data Loader for Automatic Data Point Generation

Apart from the basic set-up, specified in chapter 3.2.1, the data structures reflecting the structure of the system to be monitored must be modelled and introduced into the SCADA system. For PVSS this is done by creating data point types (DPTs), data points (DPs) and configs that represent the supervised hardware. Subsequently, these data points have to be connected to the hardware so that the available drivers can start acquiring data.

There is a general policy in the ST/MO group stipulating that configuration information for all control systems the group is responsible for must be stored in an external (off-line) database, the Technical Data Reference Database (TDRefDB). This is to avoid becoming dependent on a tool supplier and to facilitate the migration from one system to another. For this reason, all configuration information for the SPS Restart Application, i. e. DPTs, DPs, configs and comments, will first be *modelled in the TDRefDB* and subsequently be injected into the PVSS system by means of the PVSS ASCII Manager. A special *data loader for extracting information from the TDRefDB* and converting it into a format that is readable for the ASCII Manager has to be developed. The author's task with regard to the configuration database can be broken down as follows:

(a) Define and implement a database structure in the TDRefDB that is suitable for storing PVSS configuration information.
(b) Import existing configuration information from different sources into the newly created database structure.

(c) Design and implement a data loading script that extracts PVSS configuration information from the TDRefDB and generates an ASCII Manager-compatible configuration file.

3.2.4 Mimic Diagrams for the SPS Restart Application

Special attention has to be paid to the design and implementation of the user interface because this is the part of the system that operators will work with on a daily basis. For one thing, the mimic diagrams have to be self-explaining and therefore resemble existing applications' user interfaces (especially regarding colour conventions, alarm signals etc.). Furthermore, it must be guaranteed that no damage is caused by accidental errors, such as the click on a wrong button.

The main screen of the SPS Restart Application, will depict a summary of the accelerator's state on a very high level (see section 2.4 for a description of the SPS). Each of the machine's sextants and transfer tunnels will be represented by a box that is coloured in accordance with the element's current state (OK, Warning, Fault, No Data, etc.). The operator can click on each of the boxes in order to descend in the hierarchy and get a more detailed view on the sextant in question. He will then see the states of the sextant's subsystems (electricity, vacuum, demineralised water, etc.)

Although the mimic diagrams form an integral part of the SPS Restart Application, they will not entirely be implemented by the author. The author will do *one of the panels* that can serve as an example for TCR operators who will implement the application's user interface.

4. SYSTEM DESIGN

This chapter presents the approach that was chosen to solve the problem described in the previous chapter. From a software engineer's point of view, we concentrate on the system's design that specifies HOW the functional requirements settled down in chapter 3 are prepared for the implementation. The objective of the design is to create a detailed specification of tasks and to create a basis for the implementation. The codification shall become a "mechanical" task. ([Mayr, 1998]).

Before we go into detail, a global view of the SPS Restart Application is given. Figure 4-1 presents the project from three different perspectives.

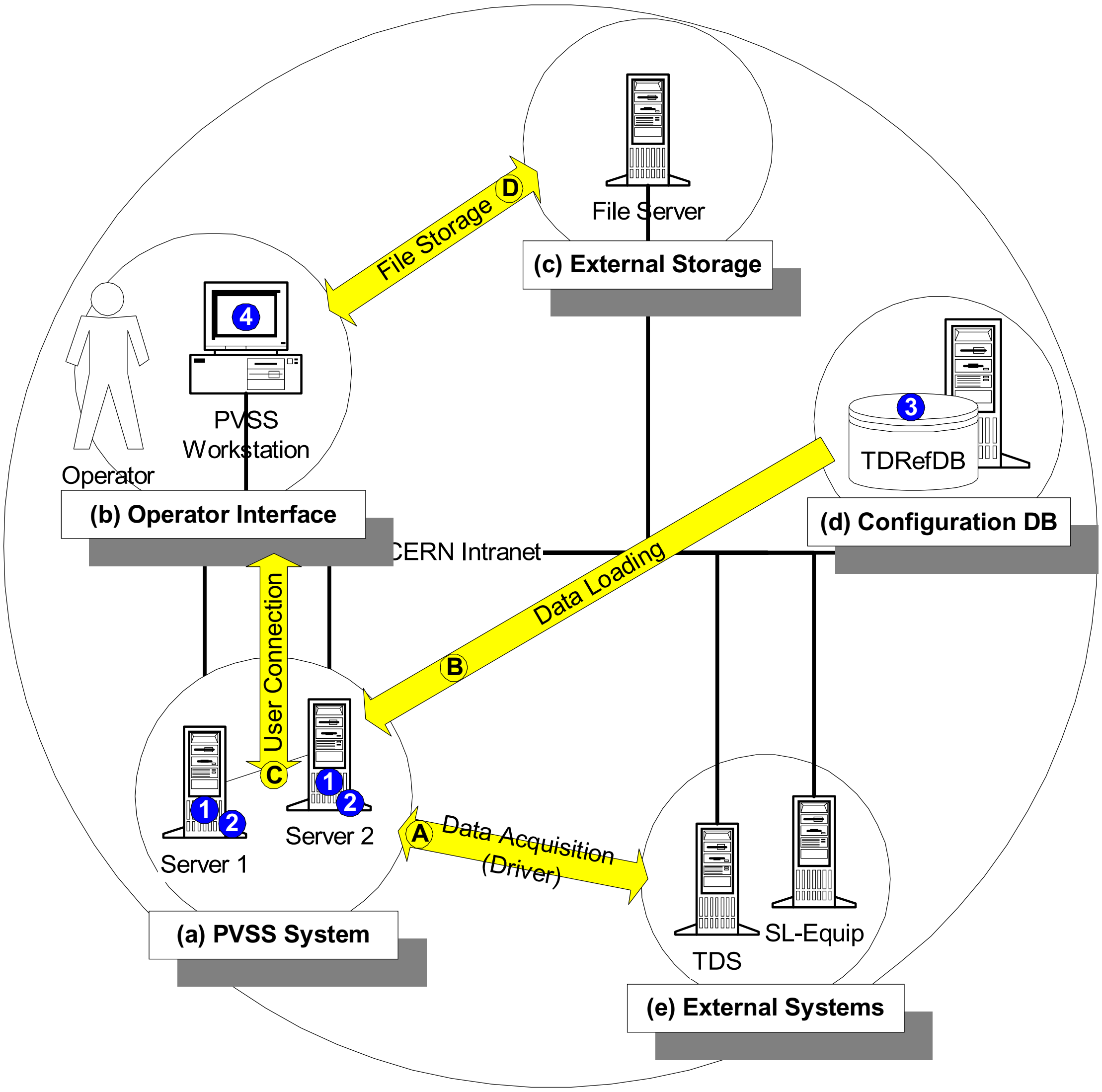


Figure 4-1 Global view of the SPS Restart Application

First of all, all *computer systems and servers* involved in the SPS Restart Application are identified:

(a) **PVSS servers.** The servers on which the operational PVSS system will be set up.
(b) **Operators' workstations.** The workstations on which the application's user interface will be running. Although the diagram only contains one workstation, an arbitrary number of user interfaces can concurrently connect to the PVSS servers.
(c) **Central file servers.** The CERN central file servers where shared components, e. g. PVSS panel and script files for the application, will be stored.
(d) **Database server.** The Oracle 8i database server hosting the TDRefDB.
(e) **External systems.** The systems that are used for communication with the SPS hardware, i. e. TDS and SL-Equip.

Second, the main *interactions* between the systems listed above are pointed out:

(A) **Data Acquisition.** This arrow describes the bi-directional connection between the PVSS system and the external systems via the TDS and SL-Equip drivers. Data is acquired from the external systems and commands are sent to equipment in the field.
(B) **Data Loading.** This arrow describes the process of loading static configuration data from the TDRefDB into the PVSS system via the PVSS ASCII Manager.
(C) **User Connection.** This arrow describes the interaction between the PVSS User Interface Manager running on the operator's workstation and the core PVSS system running on dedicated servers.
(D) **Mimic Diagrams**. This arrow describes the User Interface Manager's access to a shared PVSS project directory that is located on a central file server. The shared directory can contain mimic diagrams, scripts and colour definitions that are used by several operators working on different machines.

Third, the *parts of the project* designed and implemented by the author are highlighted. The numbers (❶❷❸❹) reflect the order in which the subtasks are treated in this document:

❶ Set-up of the PVSS system for the SPS Restart Application (section 4.1).
❷ Design and Implementation of a PVSS driver to SL-Equip (section 4.2).
❸ Development of a static PVSS configuration database (section 4.3).
❹ Design and implementation of the application's user interface (section 4.4).

4.1 System Architecture

This section contains a specification of the PVSS system's set-up, identifying the components required for the implementation of the SPS Restart Application and explaining their deployment in the operational environment. An overview of the proposed system's architecture is depicted in Figure 4-2. The motivations and considerations that have lead to this architecture are discussed in the following subsections.

4.1.1 Redundant PVSS System

In order to increase the dependability of the SCADA system, as required in 3.2.1.1, the PVSS system shall be set up in a redundant way. Since redundancy forms an integral part of PVSS II, this design decision does not require any additional development effort, apart from the installation of a Redundancy Manager and the modification of several configuration files. As mentioned in 2.2.5, a redundant PVSS system consists of two identical systems, running on two dedicated servers that are linked by redundant network connections. Redundancy thus necessitates the duplication of all hardware and software components except for the user interface and the external systems that are supervised and controlled by PVSS (TDS and SL-Equip).

4.1.2 Data Exchange

As specified in 3.2.1.2, the PVSS system for the SPS Restart Application is meant to be capable of doing data exchange with other PVSS systems at CERN. Accordingly, the SCADA will be set up in a distributed manner (see chapter 2.2.4.2), which requires the installation of a Distribution Manager and the modification of all participating systems' configuration files. The components and network lines used to establish a connection to other PVSS systems are highlighted in dark grey in Figure 4-2.

4.1.3 Data Acquisition

As mentioned earlier, data for the SPS Restart Application will be acquired from two distinct sources: the Technical Data Server (TDS) and the SL-Equip middleware (SLE). Two PVSS Driver Managers, one of them being developed in the course of this project (SLE), will perform this task. They will be installed on the same servers as the core PVSS system and are highlighted in grey in Figure 4-2.

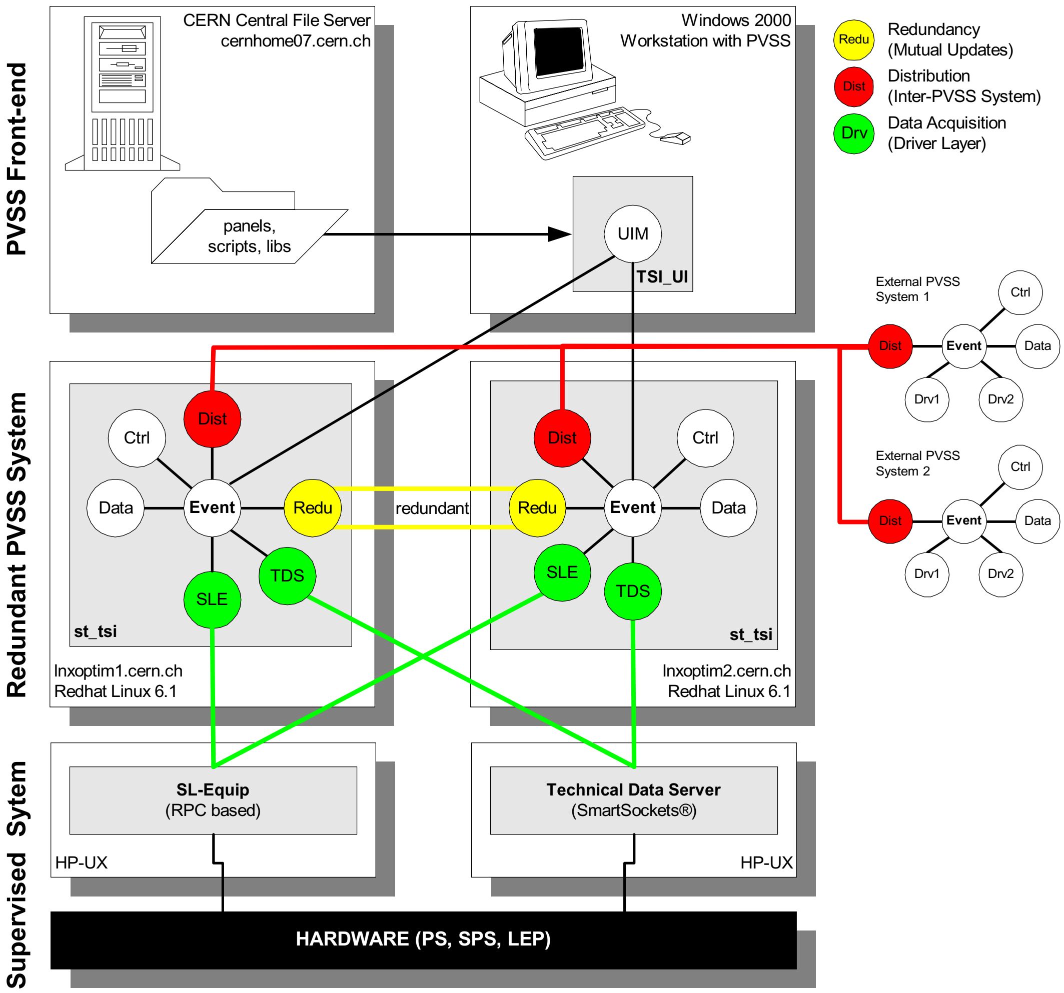


Figure 4-2 Architecture of the proposed system

4.1.4 PVSS Core System

An integration of the information provided above leads us to a core PVSS system consisting of the following components (the names in parentheses are used in Figure 4-2):

- Event Manager (Event),
- Database Manager (Data),
- Control Managers (Ctrl),
- Redundancy Manager (Redu),
- Distribution Manager (Dist),
- TDS Driver Manager (TDS), and
- SL-Equip Driver Manager (SLE).

These components will be installed on two identical Linux servers equipped with two Intel Pentium III 600 MHz processors and 256 MB RAM each. Furthermore, the machines will be equipped with two 100 MBit Ethernet cards in order to install the redundant network connection: an indirect connection via the CERN controls network and a direct peer-to-peer link. Redhat® Linux 6.1, the CERN recommended Linux distribution, was chosen as operating system for the installation.

4.1.5 PVSS User Interface

As specified in 3.2.1.3, the operators' consoles will be installed on Windows 2000® workstations in the TCR and PCR. Any other Windows NT 4.0 or Windows 2000 workstation that is connected to the CERN network and has a working PVSS installation shall be able to connect to the system as well.

Shared components, such as panels, scripts files and libraries for the SPS Restart Application, will be stored in a shared directory on a central file server. The advantage of this approach is that changes in the shared files are automatically propagated to all client machines without having to copy them. Moreover, the CERN central files servers are regularly backed up so that the risk of data loss is negligible. As each of the user interface managers needs to connect to the PVSS Event Manager using a different manager number, each operator will be assigned a series of five manager numbers for his personal use. The numbers assigned to each operator will be published on the ST/MO Web site ([WWW-STMO]).

4.2 Driver to SL-EQUIP

This section presents the design for the PVSS Driver Manager to the SL-Equip middleware. After a short general explanation of the general PVSS Driver Manager concept and the tasks to be performed by a PVSS driver (4.2.1), the design of the driver to be implemented is explicated. The specification consists of the following elements:

(1) Specification of the mapping between PVSS and SL-Equip addresses (4.2.2).
(2) Specification of the driver's class design (4.2.3).
(3) Specification of the driver's run-time behaviour by means of an object design (4.2.4).

4.2.1 General PVSS Driver Concept

The general PVSS driver is a collection of classes covering the functionality that all drivers in PVSS II should provide. It includes the following functionality:

- Initialisation of the driver's internal DPT and DP containers that will be filled with information received from the Event Manager.
- Registration with the Event Manager for the DPEs (or peripheral addresses) that are configured to communicate with the particular driver instance in question.
- Registration with the Event Manager for driver-internal DPs.
- Conversion of the internal DP names to DP identifiers (via Database Manager).
- Mapping of peripheral addresses to hardware addresses and vice versa.
- Management of requests received from the Event Manager (e.g. query the value of a particular DPE, write the value for a DPE).
- Polling.
- Transformation of hardware data formats to PVSS data formats and vice versa.
- Conversion and smoothing.
- Reconnection in case of Event Manager failure.
- Monitoring of connection(s) to hardware components ("alive" mechanism).

This functionality has been implemented using virtual functions in such a way that by deriving a separate class and defining separate functions, the driver's standard behaviour can be modified. Naturally, this shall only be done where it is absolutely necessary, e. g. for hardware-specific parts of the driver.

Figure 4-3 shows a functional diagram of a general PVSS Driver Manager, including all the tasks that are performed (a) when doing data acquisition and (b) when sending commands to the hardware.

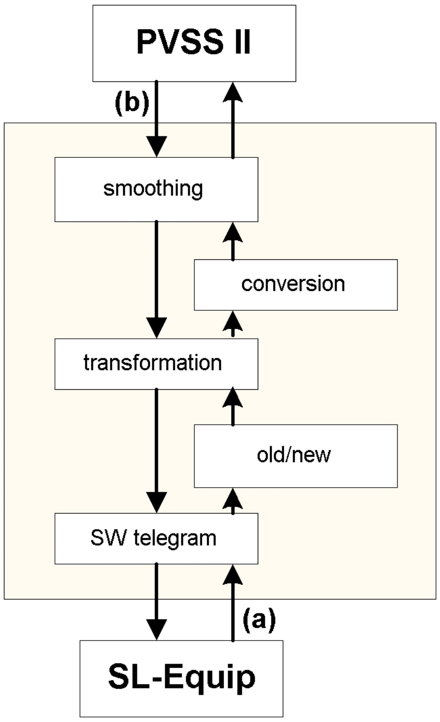


Figure 4-3 Functionality of the PVSS driver layer

Naturally, the most vital functionality provided by a driver in a SCADA system is communication with the supervised hardware/system. The general driver defines an interface to the hardware-specific part but implements it as an empty class. A specialised subclass must be derived and implemented for every real driver ([ETM, 2000]).

4.2.2 Specification of the Address Mapping

As explained in chapter 2.3.1, SL-Equip addresses (consisting of family, member, host, action and user option) have to be mapped to a different address format that is internally used by PVSS. So-called *_address* and *_distrib configs* are used for this purpose. As it was mentioned in chapter 2.2.2, configs are predefined sets of attributes that are assigned to DPs or DPEs in order to regroup configuration information for a certain purpose. The *_address config* is used for storing hardware configuration information; the *_distrib config* connects a DPE to a particular driver.

Before we define a mapping for the SL-Equip driver, however, we analyse the structure of the *_address* and *_distrib* configs, which consist of the following attributes ([ETM, 2000]):

Attribute	Type	Description
_active	`bool`	Indicates whether a DPE is active (`PVSS_TRUE`), i. e. connected to the hardware, or inactive (`PVSS_FALSE`).
_datatype	`int`	Specifies the data type of the hardware value associated to the DPE in order to perform an appropriate transformation.
_direction	`int`	Defines the input or output direction for the DPE as well as the method used (polling, spontaneous input etc.)
_drv_ident	`text`	Specifies the name of the driver to be used for data acquisition (used for automatically opening the correct configuration panel in the PARA module).
_internal	`bool`	Decides whether the DPE is internal to the driver (`PVSS_TRUE`) or connected to a hardware element (`PVSS_FALSE`).
_lowlevel	`bool`	Decides whether low-level filtering shall be performed (`PVSS_TRUE`) or not (`PVSS_FALSE`).
_mode	`char`	Deprecated, formerly used for defining the input/output type.
_reference	`text`	Reference used by the driver to access a particular hardware value.
_subindex	`uint`	Sub-index within the value addressed by _reference.
_start	`time`	Start time for polling activity.
_interval	`time`	Polling interval (in seconds).
_reply	`time`	Timeout for hardware access.
_type	`int`	Type of peripheral connection (`DPCONFIG_PERIPH_ADDR_MAIN` or `DPCONFIG_NONE`)

Table 4-1 Structure of the _address config

Attribute	Type	Description
_driver	`char`	Number of the driver that the DPE is connected to.
_type	`int`	Type of the driver allocation (`DPCONFIG_DISTRIBUTION_INFO` or `DPCONFIG_NONE`)

Table 4-2 Structure of the _distrib config

The most essential of these attributes is *_address.._reference*, for this string value is used by the driver to address a particular hardware element in SL-Equip. For this reason, all relevant

SL-Equip address information (family, member, host, action, mode and user option) needs to be coded into the _reference string. The following format was chosen for this effect:

```
family ″_″ member [″#″ host] ″_″ action ″_″ mode [″;″ useroption].
```

The *_reference* string is encoded when the user adds or modifies the *_address* config for a particular DPE. It is then transmitted to the driver concerned and, finally, decoded by the driver. The information contained is packed into a suitable SL-Equip data structure and used as a parameter in all SL-Equip library function calls.

The *_subindex* attribute will be zero by default and ignored by the driver, for it is only useful if a part of a composite value acquired from the hardware is returned to PVSS (e. g. a single bit out of a byte value). Our driver will not support this feature.

The *_active* attribute will be set `PVSS_TRUE` by default, meaning that the hardware connection is active. It can explicitly be set `PVSS_FALSE` by the user if data acquisition for a certain DPE shall temporarily be suspended.

The *_direction* attribute is very important, as it determines whether a value shall be read from the hardware or if a command shall be sent to SL-Equip. In the first case, the attribute's value is `DPATTR_ADDR_MODE_INPUT_POLL` (4), indicating that data shall be acquired via a polling mechanism and that the parameters *_start* and *_interval* shall be taken into account for determining the polling rate. In the case of sending commands to SL-Equip, the value `DPATTR_ADDR_MODE_OUTPUT_SINGLE` (5) is used.

Low-level comparison will be disabled by default. The *_lowlevel* flag will thus be `PVSS_FALSE`.

The SL-Equip driver will not require any internal DPs. The *_internal* attribute will therefore be `PVSS_FALSE` by default.

The *_mode* attribute, which has been used to specify the input/output mode in earlier PVSS versions, has been deprecated in PVSS version 2.11.1. It has been replaced by a combination of the *_active*, *_direction*, *_lowlevel* and *_internal* attributes. For reasons of backward compatibility, *_mode* will always contain the same value as *_direction*.

The attributes *_start* and *_interval* are used to set the polling rate inside the driver. Basically, the polling interval is specified in seconds. Additionally, a start time can be specified in order to allow more complex time expressions, such as "daily at midnight", "every Monday at 1:00 PM", etc. Although this feature will be implemented in order to increase the re-usability of the SL-Equip driver, it is not discussed in detail, for it is not relevant to the SPS Restart Application project.

The *_datatype* attribute will not be specified by the user but directly derived from the PVSS data type of the DPE concerned. The SL-Equip driver will support the PVSS data types listed in Table 4-3.

PVSS Data Type	Description	Value of the _datatype Attribute
`DPEL_FLOAT`	32-bit real number	`DPATTR_TRANS_FLOAT_TYPE`
`DPEL_DYN_FLOAT`	dynamic array of 32-bit real numbers	`DPATT_TRANS_FLOAT_TYPE`
`DPEL_INT`	16-bit integer number	`DPATTR_TRANS_INT16_TYPE`
`DPEL_DYN_INT`	dynamic array of 16-bit integer numbers	`DPATTR_INT16_TYPE`
`DPEL_STRING`	max. 1024-byte string	`DPATT_TRANS_VISIBLE_TYPE`

Table 4-3 Mapping of PVSS data types

As can be seen from Table 4-3, the driver will make no distinction between single values of a certain type and dynamic arrays of the same type. The difference will be handled internally by the PVSS Driver API.

According to [ETM, 2000], the *_address.._type* attribute can assume the values `DPCONFIG_NONE` and `DPCONFIG_PERIPH_ADDR_MAIN`. As all DPEs managed by the SL-Equip driver will have an associated peripheral address, they will be assigned `DPCONFIG_PERIPH_ADDR_MAIN` by default. The same goes for the *_distrib.._type* attribute, which will always be `DPCONFIG_DISTRIBUTION_INFO`.

The *_address.._drv_ident* attribute will be "SL-EQUIP". This value is used by the PVSS parameterisation module in order to determine the file name of the configuration panel to load when a user wants to view the address configuration of a DPE.

The *_distrib.._driver* attribute associates a DPE with a concrete instance of a PVSS Driver Manager. As the SL-Equip driver will connect to the Event Manager using the driver number 2, this attribute will equally be 2 for all DPEs connected to SL-Equip.

Address information for DPEs connected to the SL-Equip driver will be entered/modified by the user by means of a special PVSS panel that will be created in the course of this project and integrated into the PVSS parameterisation (PARA) module.

The address mapping defined above will be relevant to the implementation of:

- the PVSS Driver Manager described in this section,
- the off-line configuration database specified in 4.3 and
- the configuration panel for adding/modifying/removing the _address config for a DPE connected to the SL-Equip driver.

The next step in the driver design is the drawing up of an appropriate class design.

4.2.3 Class Design

As mentioned earlier, the implementation of the SL-Equip Driver Manager specified in 3.2.2 will be based on the PVSS *Application Programming Interface* (API). This set of classes, data structures and data types included in the PVSS distribution provides a standard mechanism for extending PVSS functionality. The API is implemented in C++ and available for Microsoft Windows NT 4.0 as well as Linux.

The part of the API that is meant for the development of PVSS drivers, the so-called *PVSS Driver Manager API*, is designed as an *object-oriented framework*, i. e. a set of classes that embodies an abstract design for solutions to a family of related problems, and supports reuses at a larger granularity than classes ([Johnson and Foote, 1998]). The advantage of having a framework rather than a traditional class library is that only a few classes need to be derived and some methods must be overwritten in order to obtain a fully functional driver. Functionality that is common to all PVSS drivers, e. g. communication with the Event Manager, adding/removing data points to/from the driver's internal polling list, periodic processing of the polling list etc., is incorporated in the framework; the driver developer need not re-implement it.

The most delicate task during the class design was to find out *which classes* of the framework need to be derived and *which methods* have to be overwritten. As the documentation delivered with the PVSS API is rather incomplete as far as driver programming is concerned, a thorough analysis of the framework had to be carried out before a class design could be established. The results of this analysis are presented in this section. Functionality that is implemented in the framework is only covered as far as it is relevant to the implementation of the SL-Equip driver.

4.2.3.1 Core Classes

From a user's point of view, three classes are considered as the SL-Equip driver's core:

- **The SL-Equip driver's Manager class (*SleDriver*)** is derived from the framework's *DrvManager* class and responsible for co-ordinating communication with PVSS and SL-Equip respectively. Furthermore, it contains the main loop of the SL-Equip driver, which manages its control flow (from initialisation to correct termination).

- **The Hardware Service Handler class (*SleSrvHdl*)** is derived from the framework's *HWService* class and responsible for doing data exchange with SL-Equip (initialising communication, reading the current value of a particular DPE and writing the changed value of a DPE to the hardware).

- **The Hardware Mapper class (*SleMapper*)** is derived from the framework's *HWMapper* class and performs the mapping between DP identifiers, their corresponding peripheral addresses (encapsulated in *PeriphAddr* objects) and their corresponding SL-Equip addresses (encapsulated in *SleMapObj* objects). Hence, it implements part of the address mapping specified in section 4.2.2.

The relationships between these three classes are depicted in Figure 4-4, together with their inheritance hierarchies. The base classes in the upper part of the drawing belong to the framework. Their methods are only listed as far as they are relevant to the implementation of the SL-Equip driver. The classes in the lower part of the figure (shaded in grey) have to be implemented as a part of this work. Classes with a dotted border are treated in more detail later in this chapter (see Figure 4-5 or Figure 4-6).

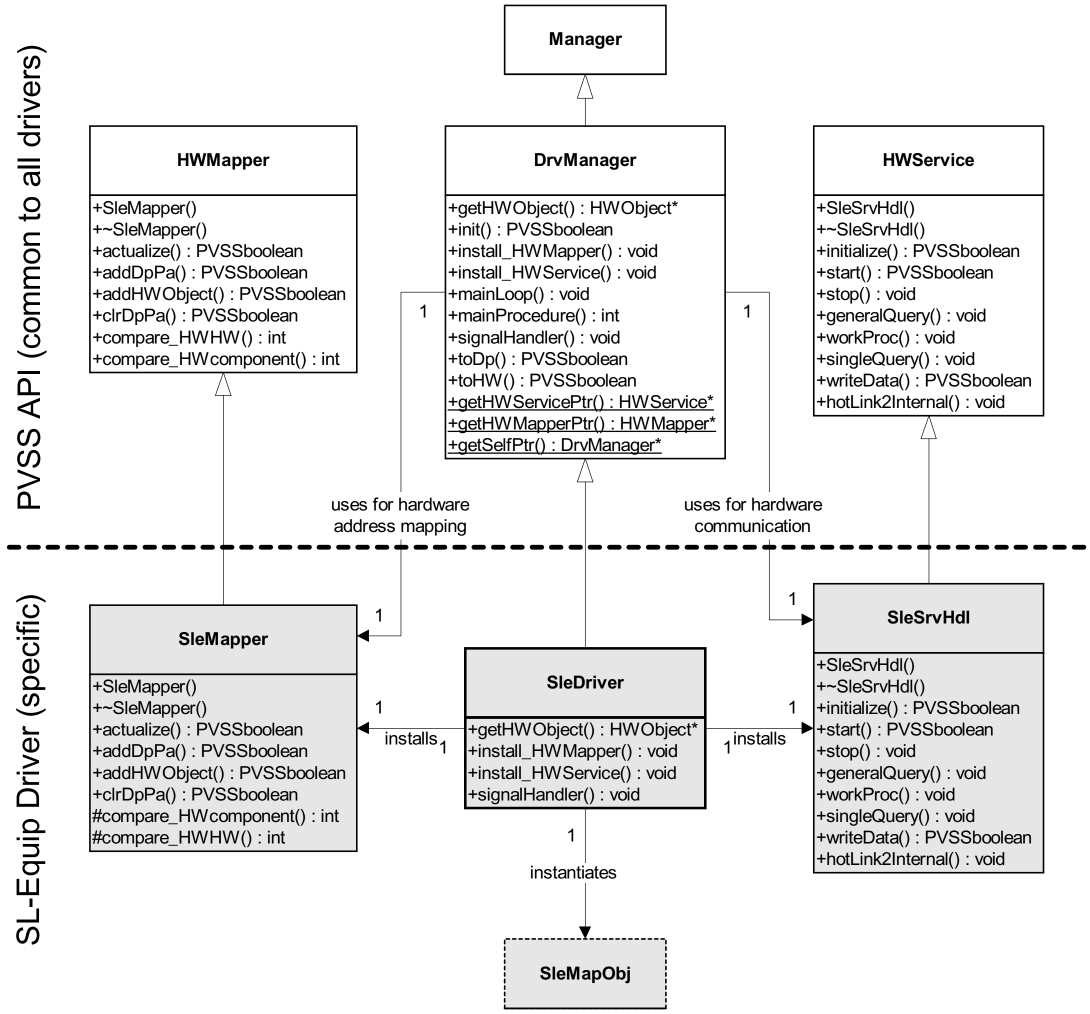


Figure 4-4 Class diagram of the SL-Equip driver's core classes

We now take a closer look at the classes mentioned above and define the functionality of their most important methods.

4.2.3.1.1 SL-Equip Driver Manager

SleDriver is the SL-Equip driver's central class. It will be derived from the framework's *DrvManager* class, which provides common functionality required by all PVSS Driver Managers. For one thing, it handles the connection to the Event and Database managers and then, it co-ordinates communication with the hardware. In other words, it encapsulates the entire control flow within a generic PVSS Driver Manager.

Four virtual methods have to be overwritten in order to replace the generic functionality by functionality that is specific to the SL-Equip Driver Manager:

- `install_HWService()` instantiates and installs the SL-Equip driver's Hardware Service Handler (*SleSrvHdl*), which is then used by the framework to co-ordinate communication with the hardware.
- `install_HWMapper()` instantiates and installs the SL-Equip driver's Hardware Mapper (*SleMapper*) that is used by framework methods to perform the mapping of PVSS to SL-Equip addresses and vice versa.

- `getHWObject()` creates new *SleMapObj* objects and returns pointers to them, following the Factory Method design pattern described in [Gamma et al., 1994].
- `signalHandler()` handles UNIX signals received by the driver.

The `install_HWService()` and `install_HWMapper()` methods are called during the driver's initialisation. They instantiate objects of derived classes and assign them to static pointers declared in the super class. This standard technique in object-oriented design allows it to replace generic functionality foreseen in the framework by a more specific implementation.

The `getHWObject()` method is called whenever the framework needs a new *HWObject*, e. g. when a new DPE is assigned to the driver.

The `signalHandler()` method is called whenever the driver receives a UNIX signal from the operating system (see [Toomey, 1995]). It handles SIGHUP and SIGTERM and calls a method of its super class for all other signals.

4.2.3.1.2 The SL-Equip Hardware Service Handler

The SL-Equip Hardware Service Handler (*SleSrvHdl*) will be derived from the framework's *HWService* class. It will implement the interface between the generic driver and the SL-Equip-specific part as far as communication with SL-Equip is concerned. As no initialisation is necessary for communicating with SL-Equip, only two virtual methods have to be overwritten:

- `singleQuery()` polls a value from SL-Equip.
- `writeData()` writes a value to SL-Equip.

Both methods receive a pointer to a *HWObject* containing the SL-Equip address of the value to be read or written as an input parameter. In the case of `writeData()`, the *HWObject* also contains the value to be written.

4.2.3.1.3 The SL-Equip Hardware Mapper

As mentioned in section 4.2.3.1, the driver's Hardware Mapper (*SleMapper*) is used for mapping PVSS to SL-Equip addresses and vice versa. For one thing, it establishes a connection between DP identifiers and peripheral addresses (i. e. the *_reference* strings contained in the *_address* config). Secondly, it manages the connection between these *_reference* strings and their corresponding SL-Equip addresses.

The following methods have to be overwritten:

- `addDpPa()` is called to add a new peripheral address (*PeriphAddr*) received from the Event Manager to the driver's internal list. Furthermore, it creates a new *SleMapObj* from the peripheral address and calls the `addHWObject` method.
- `addHWObject()` adds the *HWObject* it receives as an input parameter to the driver's internal list.
- `clrDpPa()` is called to remove a data point's peripheral address and the corresponding Hardware Object from the driver's internal lists. This is the case when the user deletes a DPE assigned to the SL-Equip driver in the parameterisation module or when he removes/changes such a DPE's *_address* config.

- `compare_HWHW()` and `compare_HWcomponent()` are used for comparing the peripheral addresses of two Hardware Objects.

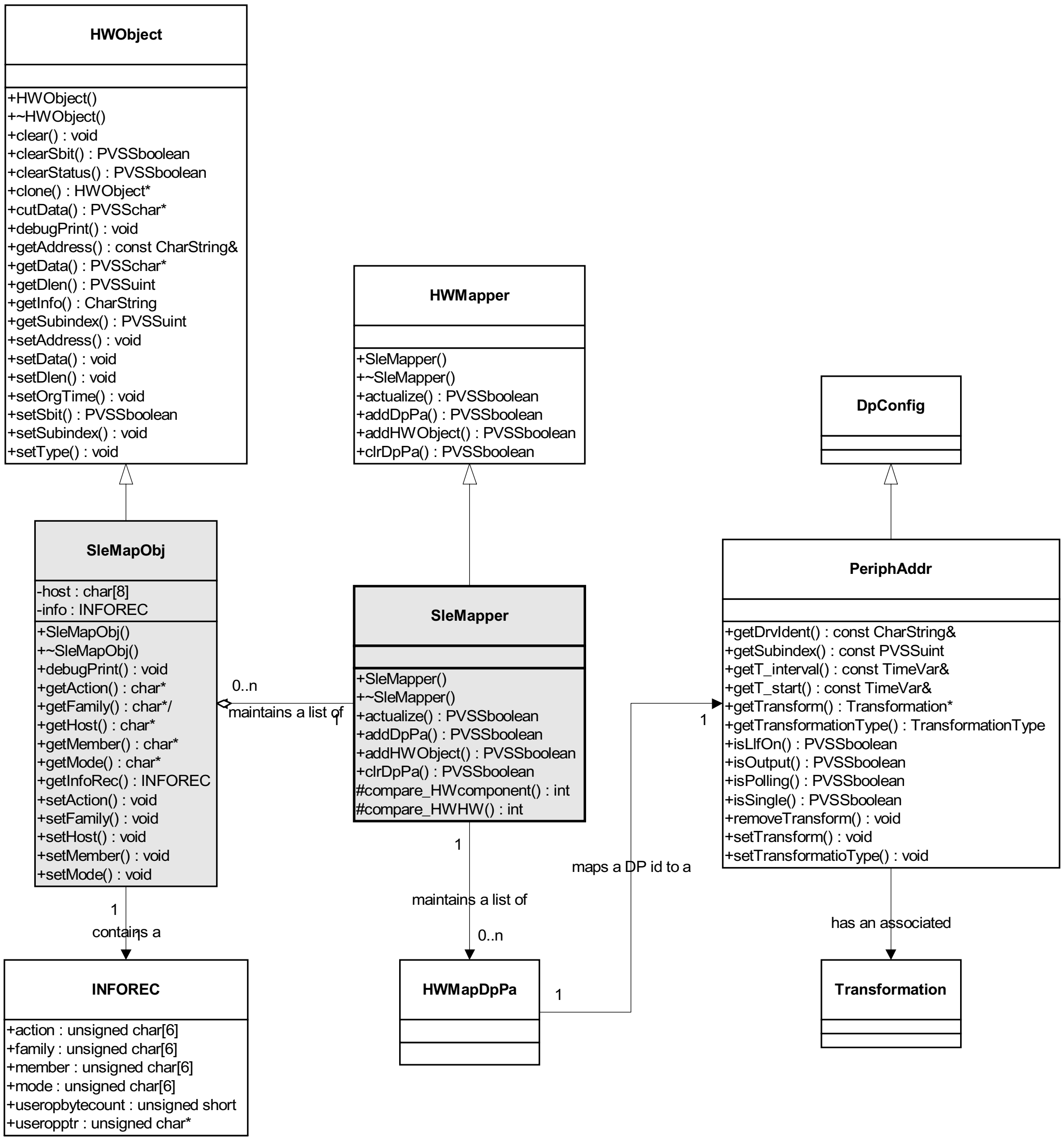


Figure 4-5 Class diagram of the SL-Equip Driver Manager (II)

4.2.3.2 Transformation Classes

Transformations describe the relationship between values obtained from external systems (SL-Equip) and their representation in PVSS. In other words, they perform the conversion of hardware values to PVSS values (in the read direction) and vice versa (in the send direction). As a result, a separate subclass of the framework's *Transformation* class needs to be implemented for each data type supported by the SL-Equip driver. As mentioned in section 4.2.2, the SL-Equip driver is meant to support the following SL-Equip data types:

- 32-bit *floating-point values* and arrays (corresponding to modes RAR and WAR)
- 16-bit *integer values* and arrays (modes RBI and WBI)
- *String values* (modes RS and WS)

The classes *SleTransFloat*, *SleTransInt* and *SleTransString* thus will be derived from *Transformation*, as shown in Figure 4-6.

The two central methods performing the data conversion are `toPeriph()` and `toVar()`:

- `toPeriph()` takes the value to be sent to SL-Equip as well as the maximum data length as input parameters, transforms the given value to an SL-Equip compatible format and returns the result to the caller via an output parameter. The method returns `PVSS_TRUE` if the conversion is successful.
- `toVar()` does exactly the opposite. It takes a buffer containing the value received from SL-Equip as an input parameter, performs a transformation and returns the result to the caller via an output parameter (*VariablePtr*). Like `toPeriph()`, it also returns `PVSS_TRUE` if the transformation is successful.

The `itemSize()` method returns the size of a single value of the data type concerned in bytes (e. g. 2 for a 16-bit integer value). It is internally used by PVSS to allocate buffer memory.

The `getVariableType()` method returns the “preferred variable type” of the *Transformation*. It is used by the framework to convert values received from the Event Manager (to be written to the hardware) to the variable type expected by the Transformation. For instance, a DPE might be of type float but the *Transformation* expects an integer value. In this case, the framework will do the conversion from float to integer before the `toPeriph()` method is called.

The `isA()` method is used for comparing a given transformation type with the type of transformation performed by the class.

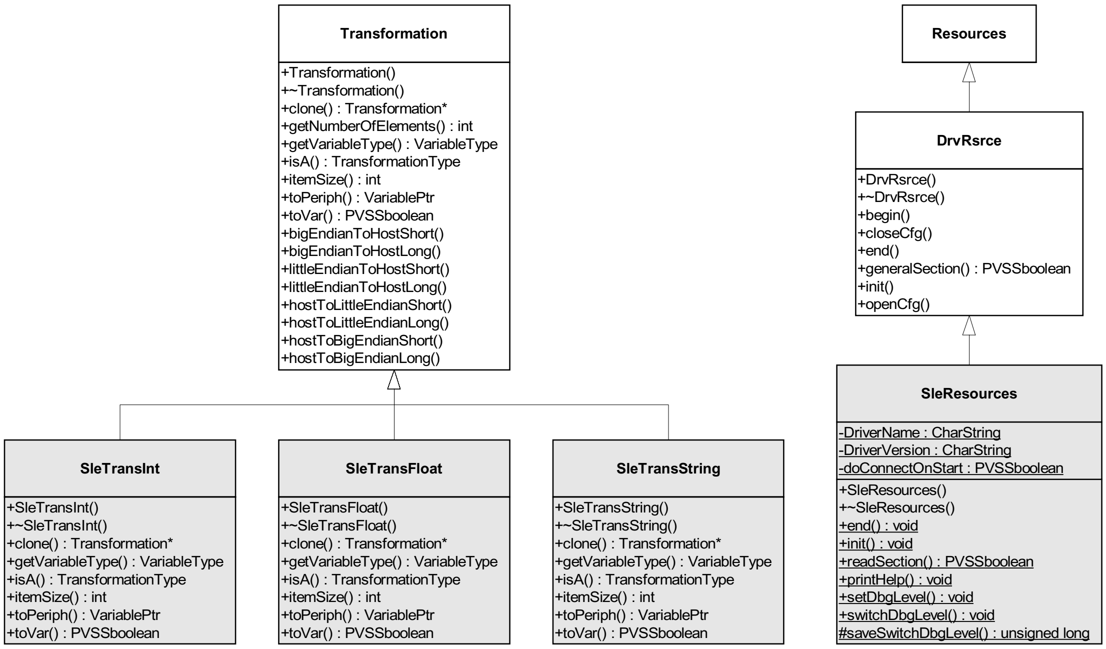


Figure 4-6 Class diagram of the SL-Equip Driver Manager (III)

4.2.3.3 Utility Classes

Two more classes have to be derived: the SL-Equip Hardware Object (*SleMapObj*) class mentioned before and the SL-Equip Driver Resources (*SleResources*) class that will read-out driver-specific configuration information from the PVSS configuration file.

4.2.3.3.1 SL-Equip Hardware Objects

The *SleMapObj* class has already been mentioned when talking about the *SleMapper* class (section 4.2.3.1.3). As shown in Figure 4-5, it is derived from the framework's *HWObject* class. Its main task is to encapsulate the address information for a single DPE. Furthermore, it contains a pointer to a buffer in which the periphery data, i. e. the value that has been acquired from SL-Equip and has to be sent to PVSS, is stored. An additional attribute contains the size of this buffer in bytes. Moreover, the class manages the DPE's transformation type and some status information indicating whether the value received from the hardware is valid or not.

Most of these attributes are general and therefore managed by the super class. However, the hardware address, which is received from the Event Manager in the form of the *_reference* string described in 4.2.2, has to be decoded and split into parts corresponding to an SL-Equip address (family, member, host, action, mode and user option). These parts will then be stored in an *INFOREC* structure defined by the SL-Equip API, which can directly be used in SL-Equip function calls.

Theoretically, the *SleMapObj* would not need any additional methods, as the *INFOREC* structure can be constructed from the *PeriphAddr* parameter passed to the classes' constructor. As the information might change later, however, `getXXX()` and `setXXX()` methods will be implemented for each part of the SL-Equip address.

4.2.3.3.2 SL-Equip Resources

The *SleResources* class is derived from the framework's *DrvRsrce* class, as shown in Figure 4-6. This class represents the driver's interface to its resources (i. e. the PVSS configuration file). As driver-specific functions primarily relate to driver-internal data points, which our driver will not have, the `begin()`, `readSection()` and `end()` methods will only contain dummy functionality.

The `setDbgLevel()` and `switchDbgLevel()` methods will be used for debugging purposes and are described in the implementation chapter.

4.2.4 Object Design

The class design contained in the previous section describes the static structure of the SL-Equip Driver Manager. This section specifies its dynamic behaviour at run-time.

During its "lifetime" (= run-time) the driver has to pass the following three phases:

(1) Initialisation
(2) Hardware activity
(3) Termination

These phases are described in the ensuing sections.

4.2.4.1 Initialisation

At its start-up, the driver instantiates its various "modules" (Resources, Driver Manager, Hardware Mapper, Hardware Service Mapper etc.) and initialises them. For the user of the framework, this is a fairly simple task:

(1) The static `init()` method of the *SleResources* class has to be called, which causes the framework to read the driver-specific section of the PVSS configuration file and to store the values found in its static member variables.
(2) A signal handler for SIGHUP and SIGTERM must be installed.
(3) An instance of the *SleDriver* class has to be created and its `mainProcedure()` method must be invoked. From this time on, the framework takes over control.

However, we also want to understand what happens internally during this initialisation phase, at least as far as the classes that have to be implemented for the SL-Equip driver are involved. This simplified initialisation process is depicted in Figure 4-7. A more complete view of the initialisation process is described below.

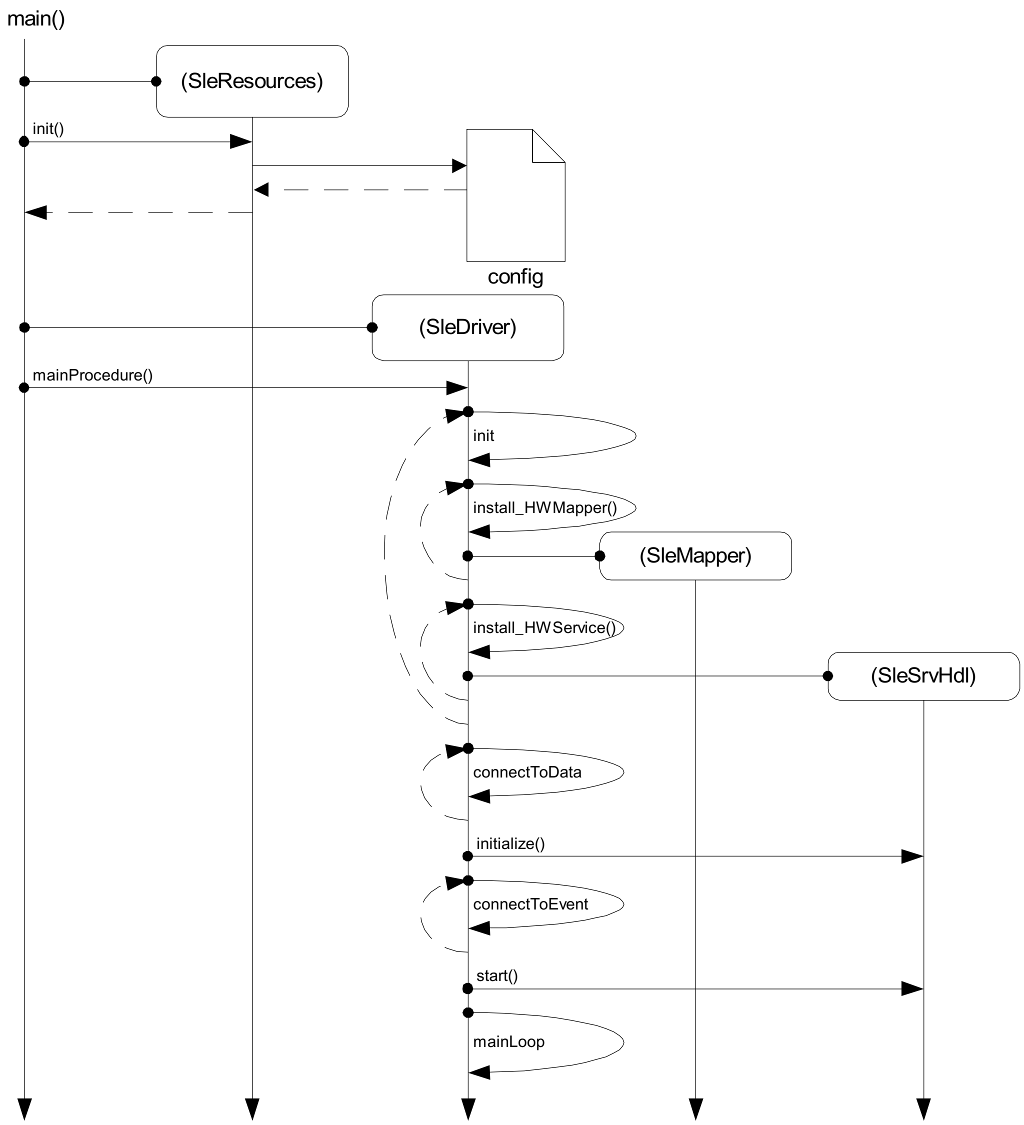


Figure 4-7 Object model of the SL-Equip driver during its initialisation

First of all, the Driver Manager's `init()` method is called, which initiates the creation of several objects:

- a DP Container (framework's *DpContainer* class)
- a DP Config Manager (framework: *DpConfigManager* class)
- an SL-Equip Hardware Mapper (our *SleMapper* class)
- an SL-Equip Hardware Service Handler (our *SleSrvHdl* class)
- a Polling List (framework's *PollList* class).

After that, the SL-Equip driver will connect to the Database Manager (`connectToData()`). As a result, it will receive the *_address* and *_distrib* configs of all DPEs connected to it. These configs will be used to build up the driver's internal lists by means of the Hardware Mapper's `addDpPa()` method.

Subsequently, the communication with SL-Equip is initialised by a call to the Hardware Service Handler's `initialize()` method. As soon as a connection to the Event Manager has been established (`connectToEvent()`), the hardware activity can be started invoking the Hardware Service Handler's `start()` method.

At this point in time, the driver has taken up its regular activity and enters in its main loop (`DrvManager.mainLoop()`).

4.2.4.2 Hardware Activity

Until it terminates, the driver remains in its main loop, in which it waits for messages from the Event Manager, checks whether DPs should be polled and cyclically calls the `workProc()` method of the SL-Equip Hardware Service Handler. This method will be empty in the SL-Equip driver's implementation because all data is acquired via the polling mechanism described below.

For handling the polling, the driver keeps an internal list in which the DPs to be polled are noted with their next polling time. When such a time is reached, the Hardware Service Handler's `singleQuery()` method is called with the Hardware Object concerned as an input parameter. The `singleQuery()` method retrieves the requested value by means of an SL-Equip function call (`EQUIP()`) and then invokes the Driver Manager's `toDp()` method in order to communicate the new value to PVSS. The `toDp()` method accepts the new Hardware Object, performs a low-level old-new comparison as needed, converts it to a PVSS-internal data format (using a suitable *Transformation* subclass, dependent on the data format), performs conversion and smoothing as necessary and sends the value to the Event Manager (if it was not smoothed away in the previous steps). After the return of the `singleQuery()` method, the new polling time for the DP is calculated and sorted into the polling list.

In the command direction, the `toHW()` method looks after the conversion of PVSS DPs to hardware objects, which are then sent to SL-Equip by the Hardware Service Handler's `writeData()` method. This method calls an SL-Equip library function (`EQUIP()`) and returns.

As mentioned above, this main loop is repeated until the driver is force to exit.

4.2.4.3 Termination

When the driver receives SIGKILL or SIGTERM from the operating system, it has to terminate. Before it exits, however, the connection to the peripheral devices (SL-Equip) must be closed down correctly. For this reason, the driver's signal handler catches SIGTERM and sets a flag in the *DrvManager* class that causes the `mainLoop()` method to return. After that, the `stop()` method of the Hardware Service Handler (*SleSrvHdl*) is called by the `mainProcedure()` before the program terminates.

4.3 Static Data Definition in an Off-line Database

This section proposes a solution to the problem described in chapter 3.2.3. First of all, a relational database structure suitable for storing PVSS configuration information has to be designed (4.3.1). After that, existing configuration information has to be analysed, validated, completed and inserted into the TDRefDB (4.3.2), and, finally, the information has to be extracted from the configuration database and imported in the SCADA system using the PVSS ASCII Manager (4.3.3).

4.3.1 Database Design

The table structure for the TDRefDB has been designed in co-operation with the ST/MO database experts, R. Martini and S. Roy, who ensured that the ST/MO group's database design standards were complied with (see 4.3.1.1).

The final objective of the database design was to *model all PVSS configuration information in a relational database structure*, so that data point types (DPTs), data points (DPs) and configs can be defined in the database, extracted to ASCII files and, finally, injected to PVSS using the PVSS ASCII Manager. A definition of the PVSS data point concept (including DPTs, DPs, DPEs and configs) was presented in 2.2.2 and shall not be repeated here.

Before we devote ourselves fully to the database structure that was designed for the PVSS data loader, we fix some general design rules that will lead us to a more homogenous database design.

4.3.1.1 General Design Rules

According to ST/MO standards, applications must never access data directly via the tables containing the records but via so-called "*user views*" that present the data in an easy-to-use format. Public synonyms for these views will be created in a separate database account. This approach considerably facilitates unforeseen modifications in the database structure at a later point in time. While underlying table structures may change, the user views on the data will always remain the same and applications using the database need not be modified. Additionally, the risk of accidental loss of data is minimised as the user views are read-only and only very few authorised users have write access to the real data.

It was decided to design the table structure for *referential integrity* rather than usability or performance. Usability will be implemented in the user views mentioned above. Since the TDRefDB is an off-line database and will only be used for periodic updates of the internal PVSS high-speed database, performance aspects are secondary. Referential integrity, however, must always be kept in mind. The user shall not be able to enter invalid values, for this will inevitably lead to problems when the PVSS on-line database is loaded with TDRefDB data.

To guarantee referential integrity without influencing the flexibility of the database design, *surrogate keys* must be used wherever possible. A surrogate key is a unique primary key generated by the DBMS (e. g. by a sequence) that is not derived from any data in the database and whose only significance is to act as the primary key. The use of surrogate keys increases the flexibility of the database design, for real data in the tables can be changed without affecting dependent records.

Furthermore, some naming conventions have been established that will make the design easier to understand and the database easier to use. The following naming conventions will be applied:

- All table names shall start with the prefix "`PVSS_`", in order to distinguish them from other TDRefDB tables. Moreover, all view names will start with "`VPVSS_`" for the same reason.
- All table and view names shall be descriptive and contain the singular name of the entity they represent. The name of the entity may be shortened only if the abbreviation is well known in the context of PVSS (e.g. DPT, DP, DPE etc.).
- Several parts of a name shall be separated by an underscore.
- All fields of a table shall start with a prefix abbreviating the name of the table or view concerned (e.g. "`dpt_`" for the PVSS_DPT table).
- Fields that are directly related to a PVSS entity, e. g. the *_type* attribute of the *_address* config, shall conserve this name in the database (e.g. `addr_type`).
- Names of UNIQUE constraints shall start with the prefix "`unique_`" and contain the names of the fields the constraint applies to.
- Names of FOREIGN keys guaranteeing the referential integrity of the database shall start with the prefix "`fk_`" and contain at least the name(s) of the referenced field(s).
- Sequences shall be named like the fields they are used for (e.g. `DPT_ID` for the field `PVSS_DPT.DPT_ID`).

Keeping these simple design and naming rules in mind, the database structure will be easy to understand and easy to use.

4.3.1.2 TDRefDB Table Structure

Based on the file format described in 4.3.3.1, the table structure depicted in Figure 4-8 was designed. It will form the basis of our off-line PVSS configuration database and will be described in this section.

Several groups of tables have been identified according to their purpose:

(1) **PVSS Reference Tables.** The tables `PVSS_DISTRIB_TYPE`, `PVSS_DPE_TYPE`, `PVSS_ADDRESS_DATATYPE` `PVSS_ADDRESS_MODE` and `PVSS_ADDRESS_TYPE` contain simple (name, value) pairs that represent PVSS constant definitions. These constants are used in PVSS to define the type of a DPE, the address mode of a driver, etc. The sole purpose of the reference tables is to guarantee the referential integrity of the database and to prevent the user from entering invalid constant values. The tables will have to be filled with data manually before any other tables can be filled.

(2) **Data Point Type Definition Tables.** Basically, DPTs are defined by their unique names and their element types. As most DPTs are structured hierarchically, however, the declaration of the DTP names and the definition of their structure have to be separated. The DPT names are therefore declared in `PVSS_DPT`, the hierarchical structure is defined in `PVSS_DPE`. Additionally, so-called type references could be created by means of the `PVSS_DPE_TYPEREF` table but this feature will not be used for the SPS Restart Application.

(3) **Data Point Declaration Table.** The definition of DPs is much simpler. A DP declaration associates a unique name with an existing DPT. This association is done in the `PVSS_DP` table.

(4) **Config Definition Tables.** Configs are sets of attributes associated with a DPE of a particular DPT instance (=DP). The *_address* and *_distrib* config are always used together. Therefore, the same table (`PVSS_ADDRESS`) can be used for their definition.

(5) **DPE Comment Table.** Like configs, comments are associated with a DPE of a particular DP. The structure of the `PVSS_DPE_COMMENT` table is thus similar to that of `PVSS_ADDRESS`.

The detailed structure of the tables mentioned above and their mutual dependencies are shown in Figure 4-8. The server model was created with Oracle Designer and will be used for automatically generating the table structure in the database.

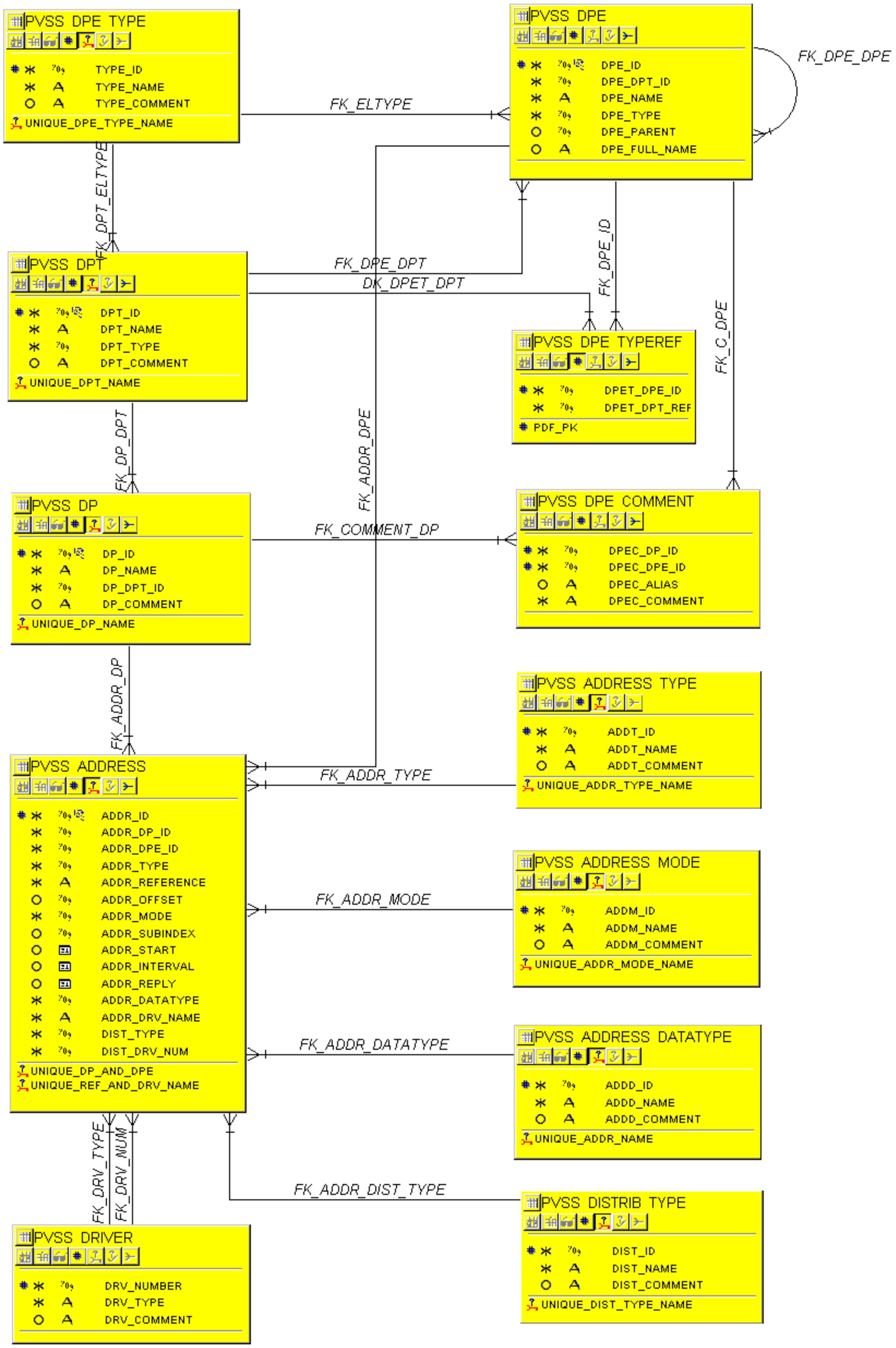


Figure 4-8 Server model of the TDRefDB table structure for PVSS configuration data

4.3.1.2.1 Reference Tables

The structure of the reference tables PVSS_DISTRIB_TYPE, PVSS_DPE_TYPE, PVSS_ADDRESS_DATATYPE, PVSS_ADDRESS_MODE and PVSS_ADDRESS_TYPE is identical:

(1) The numeric xxx_id column corresponds to the value of the PVSS constant represented by a record and forms the table's primary key. The primary key will later be referenced by other tables, notably by PVSS_ADDRESS, PVSS_DPT and PVSS_DPE.
(2) The xxx_name column corresponds to a PVSS constant's name, which must equally be unique. The column is therefore protected by a UNIQUE constraint.
(3) The xxx_comment column is optional and can contain a free textual description of the constant's purpose.

4.3.1.2.2 Data Point Type Definitions

As mentioned above, DPT definitions will require entries in two tables: PVSS_DPT and PVSS_DPE.

PVSS_DPT will contain a list of all DPT names and their associated element type from the PVSS_DPE_TYPE table:

(1) The numeric dpt_id column is the table's primary key. It does not correspond to anything in PVSS (surrogate key) and is created by the DPT_ID sequence.
(2) The dpt_name column will contain the name of the DPT. As this name has to be unique in PVSS, the dpt_name column is protected by a UNIQUE constraint.
(3) The dpt_type column defines the element type of the DPT. In most of the cases, the element type will be DPEL_STRUCT (1) from the PVSS_DPE_TYPE table and the subordinated elements will be defined in PVSS_DPE.
(4) The dpt_comment column can contain an optional comment describing the DPT in plain text.

PVSS_DPE describes the structure of the DPTs. Each PVSS_DPE record consists of the following elements:

(1) dpe_id: a unique numeric identifier for the element that will be generated by the DPE_ID sequence and is the table's primary key (surrogate key).
(2) dpe_dp_id: the identifier of the DPT from PVSS_DPT the element belongs to. This column must reference an existing DPT identifier, which is enforced by a foreign key relationship.
(3) dpe_name: that name of the DPE that has to be unique within each DPT definition. Unicity is enforced by a UNIQUE constraint on the dpe_dp_name and dpe_dp_dpt columns.
(4) dpe_type: the element's data type from PVSS_DPE_TYPE.type_id. This relationship is also enforced by a foreign key.
(5) dpe_parent: this column will be used to build hierarchical DPTs. By default, its value will be NULL. If the DPE has a different parent than the DPT itself, however, it will contain the identifier of the parent DPE. The column is protected by a foreign key to PVSS_DPE.dpe_id.
(6) dpe_full_name: the full name of a DPE can differ from its name if the dpe_parent column is not NULL. In this case, the full name will include the names of all parents up to the root, separated by dots.

The following example will illustrate how DPTs are defined in our table structure, taking a DPT definition in PVSS Data Definition format (defined in section 4.3.3.1) as a starting point.

```
TypeA.TypeA 1             # DPT declaration for TypeA which is a struct
      aFloat      22      # containing a float value called 'aFloat',
      aDFloat     6       # a dynamic array of float values and
      aStruct     1       # a substructure called 'aStruct'.
            anInt 21      # This substructure consists of an integer
            aBool 23      # and a Boolean value.
```

Listing 4-1 Example of a complex DPT definition in ASCII Manager format

In order to declare TypeA in the database, a record in the `PVSS_DPT` table has to be created (see Table 4-4). In this example, the identifier 35 is generated automatically.

DPT_ID	DPT_NAME	DPT_TYPE	DPT_COMMENT
34	…	…	…
35	'TypeA'	1	'A complex DPT example'
36	…	…	…

Table 4-4 Example of a complex DPT definition (PVSS_DPT table)

In order to define the structure of TypeA, several records have to be created in the `PVSS_DPE` table (see Table 4-5). Again, the DPE identifiers 274 to 280 are assigned automatically. They do not have any other relevance.

DPE_ID	DPE_DPT_ID	DPE_NAME	DPE_TYPE	DPE_PARENT	DPE_FULL_NAME
274	…	…	…	…	…
275	35	'aFloat'	22	NULL	'aFloat'
276	35	'aDFloat'	6	NULL	'aDFloat'
277	35	'aStruct'	1	NULL	'aStruct'
278	35	'anInt'	21	277	'aStruct.anInt'
279	35	'aBool	23	277	'aStruct.aBool'
280	…	…	…	…	…

Table 4-5 Example of a complex DPT definition (PVSS_DPE table)

We will reuse our sample DPT in the following sections, when talking about DP declarations and *_address* configs.

4.3.1.2.3 Data Point Declaration

Instantiations of DPTs, i. e. DPs, will be declared in the `PVSS_DP` table. In the database, a DP is characterised by the following four elements:

(1) `dp_id`: a unique numeric identifier created by the `DP_ID` sequence (primary key).
(2) `dp_name`: the unique name of the DP that will be used by PVSS (uniqueness enforced by a UNIQUE constraint).
(3) `dp_dpt_id`: the DPT of the DP, specified by its numeric identifier. As it must be guaranteed that the DPT associated with a DP exists, the `dp_dpt_id` column references `dpt_id` column of the `PVSS_DPT` table by means of a foreign key.
(4) `dp_comment`: an optional comment describing the DP in plain text.

In order to create an instance of our sample DPT "TypeA" (see Listing 4-1), a record in the PVSS_DP table has to be created (see Table 4-6).

DP_ID	DP_NAME	DP_DPT_ID	DP_COMMENT
1027	…	…	…
1028	'a_TypeA_DP'	35	'an instance of TypeA'
1029	…	…	…

Table 4-6 Example of a DP definition (PVSS_DP table)

As soon as a DP has been instantiated, configs and comments can be associated with its elements. This will be described in the following section.

4.3.1.2.4 Address Configuration

The PVSS_ADDRESS table represents both, the _address and the _distrib config associated to a DPE. It consists of the following fields:

(1) addr_id: a unique numeric identifier created by the ADDR_ID sequence, acting as the table's primary key (surrogate key)
(2) addr_dp_id: the numeric identifier of the DP the configs are associated with. This column references the dp_id column of the PVSS_DP table by means of a foreign key.
(3) addr_dpe_id: the numeric identifier of the DPE within the DP that the configs are associated with. This column references the dpe_id column of the PVSS_DPE table by means of a foreign key.
(4) to (15): different attributes of the _address and _distrib configs that are listed in section in Table 4-1 and Table 4-2. Some of these fields represent constants and are thus protected by foreign keys to one of the reference tables.

To create associated addresses for all DPEs of our sample data point "a_Type_DP", five records in the PVSS_ADDRESS table have to be created (see Table 4-7).

ADDR_ID	ADDR_DP_ID	ADDR_DPE_ID	…	DIST_DRV_NUM
789	…	…	…	1
799	1028	275	…	1
800	1028	276	…	1
801	1028	277	…	1
802	1028	278	…	1
803	1028	279	…	1
804	…	…	…	1

Table 4-7 Example of address configurations (PVSS_ADDRESS table)

4.3.1.2.5 DPE Comment Declaration

In principle, the structure of the PVSS_DPE_COMMENT is very similar that of the PVSS_ADDRESS table because comments are equally associated with a particular DPE of a particular DP. The table contains thus the following fields:

(1) dpec_dp_id: the numeric identifier of the DP the comment is associated with. This column references the dp_id column of the PVSS_DP table by means of a foreign key.
(2) dpec_dpe_id: the numeric identifier of the DPE within the DP that the comment is associated with. This column references the dpe_id column of the PVSS_DPE table by means of a foreign key.
(3) dpec_alias: an alias name for this DPE. This alias name must be unique; the column is thus protected by a UNIQUE constraint.
(4) dpec_comment: the free-text comment to be associated with the DPE.

The creation of comments is fairly similar to the creation of addresses. To create comments for the elements of out sample DP, the following records in the PVSS_DPE_COMMENT table have to be created (see Table 4-8):

DPEC_DP_ID	DPEC_DPE_ID	DPEC_ALIAS	DPEC_COMMENT
…	…	…	…
1028	275	'floatVal'	'a floating-point value'
1028	276	'dynFloatArr'	'a dynamic array of floats'
1028	277	'struct'	'a structure'
1028	278	'intVal'	'an integer number'
1028	279	'boolVal'	'a Boolean value'
…	…	…	…

Table 4-8 Example of DPE comments (PVSS_DPE_COMMENT table)

4.3.1.3 TDRefDB User Views

As mentioned 4.3.1.1, users will always access TDRefDB data via read-only views. The purpose of these views is to present the data in a human-readable format and to facilitate the extraction of data by means of simple SQL statements. As the views will later be used by the data extraction script (specified in 4.3.3), their structure corresponds to the columns required for generating an ASCII Manager compatible configuration file.

The server model of the views that have been designed for the PVSS database is depicted in Figure 4-9.

Figure 4-9 Server model of TDRefDB user views

The views exclusively access the tables described in the previous section and follow the naming conventions explained in 4.3.1.1.

The `VPVSS_DPT` view lists the records of the `PVSS_DPT` table's content, hiding the surrogate key and the comment column as they are not needed for data extraction.

The `VPVSS_DPE` view basically corresponds to the `PVSS_DPE` table (columns `dpe_name` and `dpe_type`). In addition, it contains the following columns:

- `dpt_name` represents name of the DPT that the DPE belongs to. To obtain this information, a join with the `PVSS_DPT` table is necessary.
- `dpt_level` represents the level of hierarchy of the DPE. The level of hierarchy is 1 for DPEs that are directly associated with a DPT, 2 for DPEs whose parent is a first-level DPE, etc.
- `dpe_reftype` references to another DPT. To obtain this information, a join with the `PVSS_DPE_TYPEREF` table is necessary. This feature will not be used for the SPS Restart Application.

The `VPVSS_DP` view corresponds to the `PVSS_DP` table. The values for the `dpt_name` column will be obtained via a join with the `PVSS_DPT` table.

The `VPVSS_ADDRESS` view selects those columns of the PVSS_ADDRESS table representing attributes of the *_address* config. Joins with `PVSS_DPT`, `PVSS_DP` and `PVSS_DPE` are necessary to populate the `dpt_name, dp_name and dpe_full_name` columns with values.

The structure of the `VPVSS_DISTRIB` view is similar to that of `VPVSS_ADDRESS`, apart from the fact that it only selects columns representing attributes of the *_distrib* config from `PVSS_ADDRESS`.

4.3.2 Data Import in the TDRefDB

This section will explain how existing data will be imported in the TDRefDB table structure described in section 4.3.1.2. First of all, an overview of the overall data loading will be presented in the ensuing section.

4.3.2.1 Overview of the Data Import Strategy

We have already defined and created a database structure that is suitable for storing PVSS configuration data. In order to fill this structure, the existing configuration information needs to be analysed and processed. As there are three distinct sources of data, three different approaches to integrate the data in the TDRefDB have to be elaborated:

(1) **TDRefDB**: Information about equipment currently managed by the Technical Data Server (TDS) is already stored in TDRefDB tables. The records concerned only need to be converted and introduced into the new table structure. Oracle Stored Procedures implemented in PL/SQL (see [Feuerstein, 1996]) will be used for this purpose.

(2) **Configuration files**: Information about electrical equipment accessed via SL-Equip is currently stored in ASCII configuration files. The data contained in these files needs to be analysed, validated, corrected and introduced in the TDRefDB. This sequence of tasks will be performed by means of Perl scripts.

(3) **Paper files**: Some configuration information, e. g. concerning vacuum equipment managed by SL-Equip, is not available electronically yet. It has to be entered in the TDRefDB manually. Alternatively, the information can also be entered in SL-Equip configuration files and injected in the database by means of the script mentioned in (2).

As soon as steps (1), (2) and (3) will be completed, we can start thinking about extracting the data from the database:

(4) The well-defined configuration data will be extracted from the TDRefDB by means of an SQL script that will generate an ASCII text file, ready to be injected to PVSS by means of the ASCII Manager.

Figure 4-10 integrates the information given above and presents an overview of the data loading strategy.

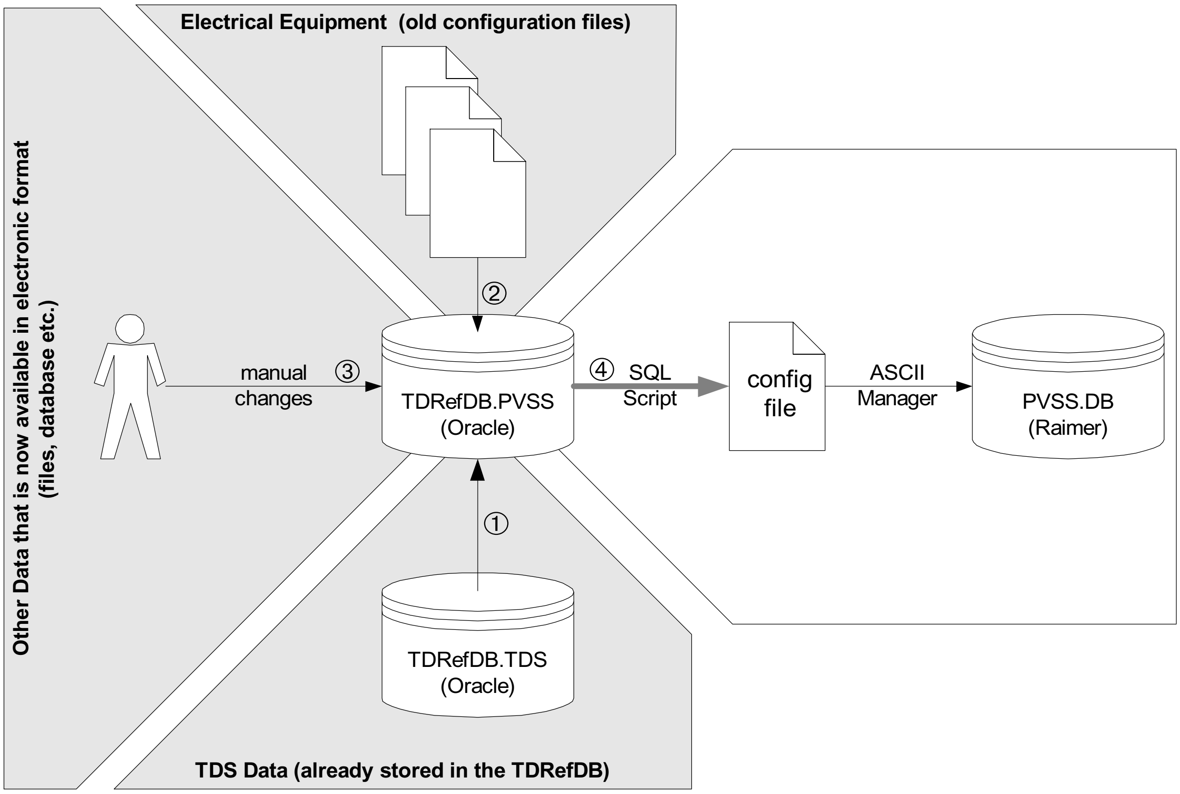


Figure 4-10 Overview of the data loading strategy

First, a method for importing TDS configuration data already contained in the TDRefDB will be described (4.3.2.1). Then, a strategy for introducing SL-Equip configuration data currently stored in ASCII text files will be developed (4.3.2.3). Finally, the way additional configuration data that is not available electronically yet will be integrated.

4.3.2.2 Import of TDS Configuration Data

As mentioned above, TDS configuration data is already stored in the TDRefDB. A view containing all TDS data to be imported in the new table structure was created by the ST/MO database experts in order to facilitate the integration process. The structure of the view is depicted in Figure 4-11.

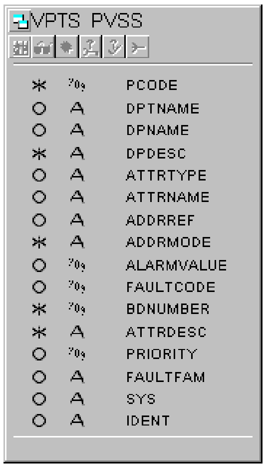


Figure 4-11 Server model of the VPTS_PVSS view

From the data contained in this view, the PVSS_DPT, PVSS_DPE, PVSS_DP, PVSS_DPE_COMMENT and PVSS_ADDRESS tables have to be filled. This is not a trivial task as the view does not contain all the information required and its structure does not at all correspond to the structure of our database.

First of all, we try to map the columns of VPTS_PVSS to the new database structure. Such a mapping is presented in Table 4-9 (VPTS_PVSS columns that are irrelevant to the data import have been omitted).

VPT_PVSS Column	PVSS Database column	Comment
dptname	PVSS_DPT.dpt_name	One PVSS_DPT record has to be created for each distinct dptname.
dpname	PVSS_DP.dp_name	One PVSS_DP record has to be created for each distinct dpname.
dpdesc	PVSS_DP.dp_comment	The dp_comment column will be taken into account when creating the PVSS_DP records.
attrname	PVSS_DPE.dpe_name	One PVSS_DPE record has to be created for each distinct combination of dptname and attrname. Additional DPEs need to be created if the addrmode column equals 'O'.
addrref	PVSS_ADDRESS. addr_reference	One PVSS_ADDRESS record has to be created for each distinct address reference (addrref).
addrmode	-	The addrmode, which can be 'I' for input or 'O' for output must be taken into account when creating PVSS_DPE and PVSS_ADDRESS records.
attrdesc	PVSS_DPE_COMMENT. dpec_comment	One PVSS_DPE_COMMENT record will be created for each distinct combination of dpname and attrname where the attrdesc column is not NULL.

Table 4-9 Mapping between the VPTS_PVSS view and the described database structure

The following subsections specify how each of the tables in the new database structure will be populated with records from VPTS_PVSS.

4.3.2.2.1 Data Point Types (PVSS_DPT)

To fill the PVSS_DPT table, it will suffice to create one record per distinct dptname in the VPTS_PVSS view. The dpe_type field will be DPEL_STRUCT (1) by default, as all TDS DPTs will have several subordinated DPEs. The dpt_comment column will simply be 'TDS' in order to distinguish TDS DPTs from DPTs representing SL-Equip data structures.

4.3.2.2.2 Data Point Elements (PVSS_DPE)

Filling the PVSS_DPE table is more complex, as not all required values are available in the VPTS_PVSS table and some assumptions have to be made to fill the remaining columns. First of all, the value for the dpe_dpt_id has to be selected from the PVSS_DPT table, which requires that all TDS DPTs have been declared in the PVSS_DPT table beforehand. The dpe_name column will correspond to values from the VPTS_PVSS.attrname column. The value of the dpe_type column has to be derived from the second letter of

VPTS_PVS.attrname for evaluations have shown that the dptype column in VPTS_PVSS does not contain accurate data types. If the second letter of attrname is 'M' or 'C', the dpe_type will be DPEL_FLOAT (22), otherwise it will be DPEL_BOOL (23). The dpe_parent column will be NULL by default if the addrmode is 'I' (for input). If the addrmode is 'O' (for output) several subordinated DPEs have to be created:

- TagName (DPEL_STRING)
- ReportCode (DPEL_FLOAT)
- ReportMessage (DPEL_STRING)

The dpe_parent of these subordinated DPEs is thus the numerical identifier (dpe_id) of the record to which they belong.

4.3.2.2.3 Data Points (PVSS_DP)

The PVSS_DP table only contains a list of all distinct dpname fields with their corresponding DPTs. The value to be entered in the dp_dpt_id column has to be selected from PVSS_DPT via the dptname, which requires that all PVSS_DPT records have been created beforehand.

4.3.2.2.4 Comments relating to Data Point Elements (PVSS_DPE_COMMENT)

The VPT_PVSS.attrdesc field will serve as a basis for filling the dpec_comment column of the PVSS_DPE_COMMENT table. As comments are attached to a precise DPE of a precise DP, it will be necessary to retrieve the correct dp_id and dpe_id for each record to be created. This necessitates that all DPEs and DPs have been declared in the database beforehand. The dpec_alias field will remain NULL by default.

4.3.2.2.5 Address and Distribution Configuration

The PVSS_ADDRESS tables will be filled on the basis of the addref column of the VPTS_PVSS view. One line in PVSS_ADDRESS will be created for each distinct address reference. As addresses, like comments, are attached to a precise DPE of a precise DP, it will be necessary to retrieve the correct dp_id and dpe_id for each record to be created. How the remaining columns are populated is specified in section 4.2.2 (*address mapping*).

The import of TDS configuration data will be performed by a set of Oracle Stored Procedures implemented in PL/SQL. We will come back to these procedures in the Implementation chapter (5).

4.3.2.3 Import of SL-Equip Configuration Data

SL-Equip configuration information that is currently stored in ASCII text files must also be introduced in the TDRefDB database structure described above. Before the data can be imported, however, the configuration files need to be analysed, corrected and completed. The following section (4.3.2.3.1) will present an analysis of the SL-Equip file format. After that, a strategy to validate and correct the information contained in the existing configuration files is described (4.3.2.3.2). Finally, the methods that will be used to import the data in the TDRefDB will be presented (4.3.2.3.3).

4.3.2.3.1 Analysis of the SL-Equip File Format

Before the files could be processed, an analysis of the proprietary file format had to be performed. The results of this analysis are shown in Listing 4-2, which contains an EBNF representation of the grammar describing the file format's syntax[3]:

```
file_set          =     { file }-;
file              =     equipment_rec, { "NEWLINE", equipment_rec};
equipment_rec     =     equipment, " ", action_list;
equipment         =     member, "/", family_part, " ",
                        family, "_", member;
action_list       =     { " ", action }-;
action            =     {letter}3;
family_part       =     alphanum, alphanum;
family            =     letter, { alphanum }5;
member            =     alphanum, { alphanum }5;
alphanum          =     digit | letter;
letter            =     "A" | "B" | … | "Z";
digit             =     "0" | "1" | … | "9";
```

Listing 4-2 EBNF representation of the SL-Equip configuration file format

Put another way, the file format is line-based, where each line represents one complete equipment record. An equipment record consists of an equipment name (specified in two different formats) and a list of supported actions, separated by spaces. We will make use of this knowledge when designing an algorithm for validating the given information.

4.3.2.3.2 Validation and Correction of the Given Information

Before the configuration data can be introduced in the TDRefDB, it has to be validated, corrected and completed, for the available configuration files have not been updated for many years. A Perl script transforming the set of outdated configuration files into a single updated configuration file will be implemented.

The algorithm to be implemented in the script will execute the following three steps:

(1) Read the set of configuration files and merge the information.
(2) Validate the given address information, correct and complete it (as far as possible).
(3) Export a new single configuration file that contains all the corrected SL-Equip configuration data.

4.3.2.3.3 Insertion in the TDRefDB

The contents of the corrected SL-Equip configuration file resulting from the processing described in the previous section will be introduced in the TDRefDB database structure described in 4.3.1.2. Another Perl script making extensive use of the Perl Database Interface (see [Jepson et al., 2000]) will be implemented for this purpose.

[3] Please note that (expression)$_x$ stands for a "repeat the *expression* in parentheses exactly x times" and { expression }$_x$ denotes "repeat the *expression* in braces zero to x times".

4.3.3 Data Export From the TDRefDB to ASCII Manager File Format

All PVSS configuration data that is accessible from the TDRefDB user views described in section 4.3.1.3 needs to be extracted from the TDRefDB and exported to ASCII Manager compatible files These files will then be used for regular updates of the PVSS on-line database, as illustrated in Figure 4-10. Before the script could be designed, however, the file format required by the ASCII Manager had to be analysed. The results of this analysis are presented in the ensuing section.

4.3.3.1 Analysis of the ASCII Manager File Format

The ASCII Manager file format is very versatile. All configurations of DPTs, DPs and configs that can be created via the PVSS user interface (PARA module) can equally be defined as ASCII files and the created automatically using the ASCII Manager. Examples of supported features are listed below:

- DPTs with an arbitrary number of DPEs can be defined.
- PVSS supports 46 different scalar and compound data types for DPEs.
- DPTs can be hierarchically structured and reference other DPTs that are then included in the type definition.
- Up to 20 different configs can be associated with DPs and DPEs.
- Configs consist of 2 *(_distrib*) to 78 *(_alert_hdl*) attributes each.
- Alias names and comments can be defined for each DP and each DPE.
- etc.

It goes without saying that this flexibility considerably increases the file format's complexity. As we will not need all of the features mentioned above in the course the SPS Restart Application, we will limit the scope of our database design to the following four features:

(1) Definition of an arbitrary number of hierarchically structured DPTs.
(2) Definition of DPs for the DPTs defined in step (1).
(3) Definition of _address and _distribution configs for DPEs.
(4) Definition of comments and alias names for DPs and DPEs.

Regardless of these limitations in scope, the table structure must be flexible enough to incorporate further _configs later. The design that is used to represent the *_address* and *_distrib* configs shall be applicable to other configs attached to DPEs in a similar manner.

Listing 4-3 describes the format of the input files required by the PVSS ASCII Manager. The Extended Backus-Naur Form (EBNF), a syntactic metalanguage for writing down the grammar of a context-free language ([Scowen, 1998]), was chosen to represent the syntax of the file format resulting from the analysis.

```
File          = { Section }-;
Section       = (DPTSect | DPSect | ConfigSect | CommentSect), "\LF";

(* Section for defining DPTs *)
DPTSect       = DPTHdr, {DPTLine}-;
DPTHdr        = "TypeName", "\LF";
DPTLine       = ( DPTName, DPEType, "\LF" ) |
                ( DPTName, "1", "\LF", {DPELine}- ) ;
DPELine       = "\Tab", DPEName, DPEType, "\LF";
DPEType       = ("41", ":", DPTReference) |
```

```
                SimpleDPEType | ArrayDPEType | StructureDPEType;
DPTReference= DPTName;
DPTName      = PVSSidentifier;
DPEName      = PVSSidentifier;

(* Section for creating DPs of existing DPTs *)
DPSect       = DPHdr, { DPLine }-;
DPHdr        = "DpName", "\Tab", "TypeName", [ "\Tab", "ID" ], "\LF";
DPLine       = DPName, "\Tab", DPTName, [ "\Tab", DPID ], "\LF";
DPName       = PVSSidentifier;
DPID         = IntegerNumber;

(* Section for creating configs for existing DPs and DPEs *)
ConfigSect   = DistribConf | AddressConf;

(* Section for defining the attributes of the _distrib config *)
DistribConf  = DistribHdr, { DistribLine }-;
DistribHdr   = "ElementName", "\Tab", "TypeName", "\Tab",
               "_distrib.._type", "\Tab", "_distrib.._driver", "\LF";
DistribLine  = ElementName, "\Tab", DPTName, "\Tab",
               DistribType, "\Tab", "\", DriverNum, "\LF";
ElementName  = DPName, ".", DPEName;
DistribType  = ("0" | "56");
DriverNum    = IntegerNumber;

(* Section for defining the attributes of the _address config *)
AddressConf  = AddressHdr, { AddressLine }-;
AddressHdr   = "ElementName", "\Tab", "TypeName", "\Tab",
               "_address.._type", "\Tab",
               "_address.._reference", "\Tab",
               "_address.._offset", "\Tab",
               "_address.._subindex", "\Tab",
               "_address.._mode", "\Tab", "_address.._start", "\Tab",
               "_address.._interval", "\Tab", "_address.._reply",
               "\Tab", "_address.._datatype", "\Tab",
               "_address.._drv_ident", "\LF";
AddressLine = ElementName, "\Tab", DPTName, "\Tab", IntegerNumber,
               "\Tab", DBQString, "\Tab", IntegerNumber, "\Tab",
               IntegerNumber, "\Tab", AddressMode, "\Tab", TimeValue,
               "\Tab", TimeValue, "\Tab", TimeValue, "\Tab",
               IntegerNumber, "\Tab", DBQString, "\LF".
AddressMode = "\", IntegerNumber;

(* Section for defining comments and alias names for DPs and DPEs *)
CommentSect  = CommentHdr, { CommentLine }-;
CommentHdr   = "AliasId", "\Tab", "AliasName", "\Tab",
               "CommentName", "\LF";
CommentLine  = (DPName | ElementName), "\Tab"
                AliasName, "\Tab", DBQString, "\LF";
AliasName    = PVSSidentifier;
```

Listing 4-3 EBNF representation of the ASCII Manager file format

Remarks on the EBNF listed above:

The *terminal symbol* "\LF" denotes a new line in the text file, "\Tab" denotes a tabulator. The following *non-terminal symbols* are not resolved in the above grammar:

- `PVSSidentifier`: a character string containing the name of a DPT, DP or DPE. For restrictions applying to PVSS identifiers, please refer to [ETM, 2000].

- `DBQString`: a double quoted character string (e.g. “a double quoted string”).
- `SimpleDPEType`, `ArrayDPEType`, `StructureDPEType`: a numeric identifier for a PVSS DPE Type (e. g. float, time, dynamic array of integers, structure of strings, generic structure etc.). For a complete list, please refer to [ETM, 2000].
- `IntegerNumber`: any positive integer number.

As can be seen from Listing 4-3, the ASCII Manager file format is column- and line-based. That means that different pieces of information belonging to the same definition, e. g. name and numerical identifier of a DP, are separated by a single white-space character (e. g. a tabulator). Two definitions are always separated by a line feed. All sections containing definitions of the same type, e. g. DPT definitions, DP definitions etc., are preceded by a header line describing the structure (i. e. the sequence of fields) of the following definitions.

4.3.3.2 Specification of the Data Extraction Script

This extraction will be performed via an SQL script that makes use of the advances features of the Oracle SQL*PLUS environment. The required information will be selected from the views *in the correct format* and directly spooled to a text file.

4.4 Mimic Diagrams

The design of the user interface for the SPS Restart Application is described in this section. As mentioned in the problem description, the user interface will consist of a series of PVSS panels displaying the current status of the systems involved in the SPS start-up (see 3.2.4). The primary objective of the SPS Restart Application is to allow for TCR and PCR operators to determine in a very efficient way if the SPS is ready to produce a beam. If all the machine’s sextants are in state “OK”, which means that all the sextants’ subsystems are “OK”, the machine can enter the state “BEAM in TT 10”. This means that the beam produced by the PS can be injected into transfer tunnel 10, which then feeds the SPS ring itself (see Figure 4-12 for a schematic representation of the SPS complex).

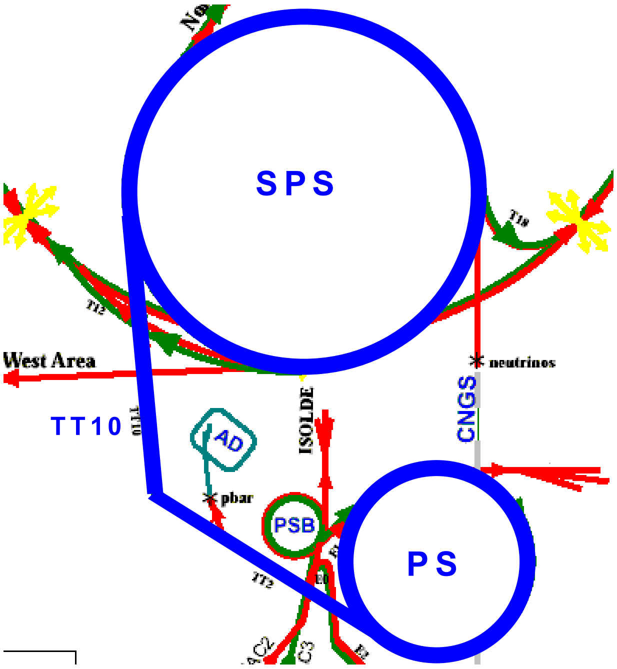


Figure 4-12 Schematic representation of the SPS complex

As required in 3.2.4, only *one* of the panels will be designed and implemented by the author whereas the complete series of mimic diagrams will later be developed by TCR operators who know the systems involved in the SPS start-up much better. The goal of this thesis is to prepare the development of the user interface in a way that the panel created by the author can serve as an example for the development tasks to be performed by the operators.

As mentioned in chapter 3, the *start-up screen of the SPS Restart Application* shall give an overview of the SPS complex and reflect its status on a very high level (e. g. one box per sextant (BA) and one box for each system that is common to all sextants). By clicking on one of the BAs, an animated functional diagram of the sextant in question shall be displayed. This functional diagram shall display the sextant's subsystems (e.g. raw water, demineralised water, power supplies, main magnets etc.) as well as their current state.

An example of a functional diagram that has been developed in the course of the GTPM project and that shall serve as a basis for the development of the user interface is shown in Figure 4-13. For a description of GTPM and the complete series of functional diagrams in Excel format, please refer to [WWW-STMO].

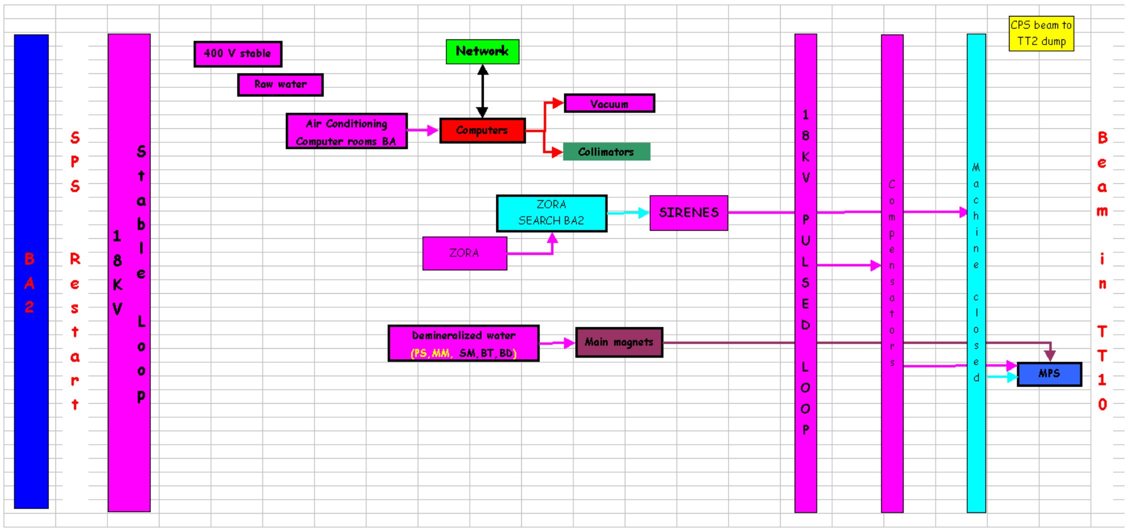


Figure 4-13 Functional diagram for SPS BA2

Figure 4-13 represents the subsystems of SPS sextant 2 (BA2), including their mutual dependencies. The colours used in the diagram stand for the organic units at CERN that are responsible for (emergency) intervention in case of a breakdown of the system concerned. The meaning of the boxes represented in the diagram and their dependencies will not be explained in detail. We will content ourselves with knowing that the functional diagrams shall serve as a basis for the implementation and that the state of all the subsystems represented in the diagrams should also figure in the SPS Restart Application's panels.

In order to guarantee a consistent look-and-feel throughout all the mimic diagrams of the application, a set of *user interface guidelines* had to be established. The objective of these guidelines is to make the panels easy to "read" (self-explanatory) and thus easy to use for the operators. In addition to some font and layout definitions that shall not be treated here, a set of colour codes for representing equipment states has been defined. These colour codes are presented in Table 4-10.

State	Colour	Description
ST_OK	green	The system in question is OK and switched on. It is thus working normally.
ST_OFF	white	The system in question is OK but switched off. It is thus inactive for the moment.
ST_WARNING	yellow	The system has a problem (e. g. a critical temperature has been reached) but is still working.
ST_FAULT	red	The system in question is in a bad state and not working any more.
ST_NO_DATA	blue	The current state of the system cannot be determined (e.g. due to a hardware, transmission or driver problem).
ST_INHIBITED	grey	The equipment is out of service (e.g. for maintenance).
ST_NOT_ANIMATED	dark grey	

Table 4-10 Definition of system states and colour codes

The most essential and at the same time most difficult task during the panel design was to *analyse and understand how the states of all the subsystems can be determined*. First, all hardware elements related to a subsystem (e.g. voltmeters, breakers etc.) had to be identified in co-operation with TCR operators. Second, the PVSS DPE representing these hardware elements had to be determined and finally, a set of conditions had to be defined for each subsystem in order to find out whether the system is OK, OFF, FAULTY etc.

An example of such an analysis will be given in section 5.4 of the following chapter, where the implementation of the user interface panel is explained.

5. IMPLEMENTATION

Following the software project lifecycle, this chapter describes the technical details of the project's implementation, based on the results of the detailed design presented in chapter 4.

5.1 System Architecture

The PVSS system for the SPS Restart Application was implemented exactly as specified in chapter 4.1. No additional software development was required for the system's set-up apart from the modification of several operating system settings and the adaptation of PVSS configuration files. How PVSS is installed in a redundant and distributed way is well documented in [ETM, 2000] and shall not be treated here. All the same, we want to summarise the tasks that had to be performed for the implementation of the PVSS core system on the redundant Linux servers and for the installation of a PVSS user interface on a Windows NT Workstation. Figure 5-1 gives an overview of the whole PVSS system implemented for the SPS Restart Application.

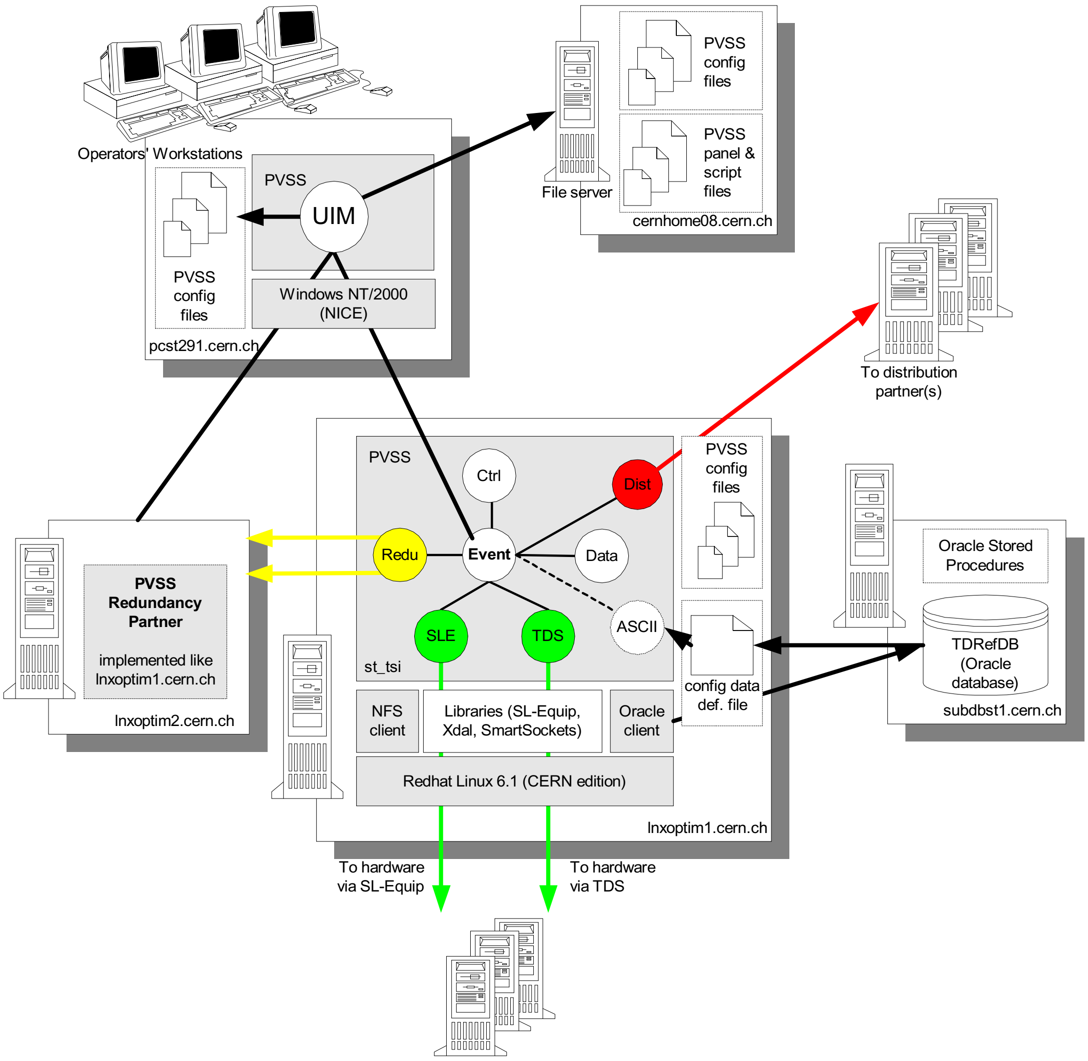


Figure 5-1 Overview of the PVSS system's implementation

Figure 5-1 is a synopsis of Figure 4-1 and Figure 4-2 of the System Design chapter, complemented by the names of the servers and by the software parts and configuration files that had to be installed on each of the computers. The machines represented by boxes have been modified by the author whereas machines represented by pictograms have been used "as-is" – as external systems.

5.1.1 Set-up of the Redundant Linux Servers

This section presents a list of all tasks that had to be performed to make the core PVSS system for the SPS Restart Application run, as specified in 4.1.4. Both Linux servers, *lnxoptim1* and *lnxoptim2,* have been configured identically.

5.1.1.1 Additional Hardware Installation

In addition to the hardware specified in section 4.1.4, the following components had to be installed:

- Two 100 MBit network adapters on each of the servers.
- A direct connection between the two servers.
- A connection to the CERN network for each of the servers.

5.1.1.2 Software Installation

- Installation of Redhat Linux 6.1, including CERN-specific packages (see [WWW-CERNLNX]).
- Installation of PVSS II 2.11.1 (see [ETM, 2000]).
- Installation of the libraries required by the TDS and SL-Equip drivers (i. e. SL-Equip, Xdal and Talarian SmartSockets®).
- Installation of the TDS Driver Manager developed at CERN.
- Installation of the SL-Equip Driver Manager developed in the course of the SPS Restart Application project (see section 5.2).
- Installation of the database loader script specified in section 5.3.

5.1.1.3 Software Configuration

- Creation of a user account for the PVSS project.
- Creation of a PVSS project (called `st_tsi`) in the PVSS user's home directory.
- Modification of the project's configuration files to activate redundancy and distribution features. Relevant parts of the configuration files concerned are listed in Appendix A.
- Creation of NFS mount points for the project directories of the redundancy partners (*lnxoptim1* mount *lnxoptim2* and vice versa). These remote directories will be used for synchronising with the on-line database of the redundancy partner on start-up.
- Modification of the shell environment of the PVSS user (activation of Oracle network installation, setting of PVSS-specific environment variables, paths etc.)
- Extraction of static configuration data from the TDRefDB (by means of the database loader script described in section 5.3.).
- Injection of static configuration data (DPT, DP, DPE and config definitions) in PVSS by means of the PVSS ASCII Manager.

5.1.2 Set-up of the Windows NT Workstations

The set-up of the NT Workstations for running the PVSS user interface was much simpler. No additional hardware was required. The following task list is based on the assumption that the PVSS user interface project is set up on a workstation with a standard CERN Windows NT 4.0 installation (including network access).

5.1.2.1 Software Installation

- Installation of PVSS II 2.11.1 (see [ETM, 2000]).

5.1.2.2 Software Configuration

- Mounting (mapping) of the file server's network share containing PVSS panels, scripts etc.
- Creation of a PVSS II user interface project (see [WWW-ITCO]).
- Modification of the project's configuration files to load panels and scripts from the file server and to connect to the redundant PVSS servers.

5.2 Driver Implementation

This section covers the implementation of the PVSS Driver Manager to SL-Equip as specified in section 4.2. Class design and run-time behaviour (object design) of the driver have been described in the *System Design* chapter; we only concentrate on implementation issues that have not been treated in sufficient detail. Some interesting details of the implementation are highlighted, e.g. how UNIX signals are used for debugging purposes, how a connection to SL-Equip is established and how the driver's internal DP lists are managed.

5.2.1 Implementation Constraints

The SL-Equip driver has been implemented in C/C++, using the PVSS and SL-Equip Application Programming Interfaces (APIs). Wind River's SNiFF+™ tool, an *Integrated Development Environment* (IDE) for C, C++, Java, Fortran and CORBA IDL, was chosen for source code editing, for it is one of the most powerful IDEs available on Linux. One of the Linux servers described in the previous section was used as a development machine in order to guarantee that the driver is developed and tested in the same environment in which it will later become operational. The driver was compiled and linked with the Gnu C++ compiler (`g++`), using the standard UNIX `make` tool rather than the make utility provided by Sniff. The *C++ programming and documentation guidelines* provided by ETM ([WWW-ITCO]), which have been developed for the implementation of the PVSS API, have equally been applied for the development of the SL-Equip driver.

Doc++, a documentation system for C/C++ and Java generating both, LaTeX output for high quality hardcopies and HTML output for online browsing (see [WWW-DOC++]), has been used for automatically generating a system documentation for the SL-Equip driver. The documentation was extracted from special JavaDoc-style comments in the C++ header files.

5.2.2 Implementation of the Classes

The structure of this section corresponds to the structure of the classes required for the implementation (see 4.2.3), starting with the driver's core class: *SleDriver*.

5.2.2.1 SleDriver

As mentioned in 4.2.3.1.1, the SL-Equip Driver Manager (*SleDriver*) class is the heart of the driver, managing the control flow of the process as well as the connection to PVSS and to the periphery.

The implementation of the `install_HWService()`, `install_HWMapper()` and `getHWObject()` methods is obvious from their specification. We will thus concentrate on the `signalHandler()` method that handles two signals received from the operating system:

- `SIGTERM` (15) is received when the driver is supposed to terminate.
- `SIGHUP` (1) is received in case of a hang-up of the controlling terminal. As the SL-Equip driver will run as a background process, there is no need to handle `SIGHUP`. The signal has thus been redefined as a "`SIGDEBUG`" that causes the driver to switch on/off debug messages.

How the signal handler was implemented is shown in Listing 5-1. When `SIGTERM` is received, the driver's internal mode is set to `DRVMODE_EXITING`, which causes the `mainLoop()` method to exit and the driver to close down all its connections before it terminates, as described in 4.2.4.3. When `SIGHUP` is received, the `switchDbgLevel()` method of the *SleResources* class is called. This method changes the value of the `Resources::dbgLevel` class variable that is checked each time before debug messages are issued. This feature is very practical, for the user can switch on/off debugging by sending a `kill -1` to the process from the command line, without having to stop/restart the driver. As a consequence, the current process image is not lost and the debug messages written to the driver's log file perfectly reflect the situation that has lead to a problem. All other signals are handled by the super class of *SleDriver*.

```
#include <signal.h>

jmp_buf SleDriver::jumpBuf;

void SleDriver::signalHandler( int signal ) {
  switch (signal) {
    case SIGHUP:
      SleResources::switchDbgLevel();
      cerr << "Debug mode " <<
       (Resources::getDbgLevel() ? "ENABLED." : "DISABLED.") << endl;
      break;
    case SIGTERM:
      cerr << "exiting - please wait ...";
      internalMode = DRVMODE_EXITING;
      longjmp(jumpBuf, 1);
      break;
    default:
      DrvManager::signalHandler(signal);
  } // switch
} // signalHandler()
```

Listing 5-1 Implementation of the signalHandler method (SleDriver class)

5.2.2.2 SleResources

As specified in section 4.2.3.3.2, the *SleResources* class manages static driver configuration information. Its methods read driver-specific sections of the PVSS configuration file and store its content in static class variables.

As the SL-Equip driver does not need any additional information from the configuration file, the methods `begin()` and `readSection()` contain a dummy implementation. Hence, the methods of interest are those that are used for the implementation of the debugging mechanism mentioned in the previous section:

- The `end()` method is supposed to override configuration options specified as command line parameters. Since the SL-Equip driver does not need to override any of these options, it simply calls the `end()` method of the super class (*DrvRsrce*). Subsequently, the currently set debug level (`dbgLevel`) is read out and an additional class attribute (`SleResources::saveSwitchDbgLevel`) is set depending on this value. If debugging is active (`dbgLevel > 0`), the `saveSwitchDbgLevel` attribute is set 0, otherwise 1. The `saveSwitchDbgLevel` variable is used to toggle debugging on/off in the `switchDbgLevel` method.
- The `setDbgLevel()` method sets the driver's internal debug level by assigning a positive integer value to the `Resources::dbgLevel` class member.
- The `switchDbgLevel()` method exchanges the current value of the `dbgLevel` variable with the value of `saveSwitchDbgLevel` (toggle functionality). The method is called by the handler for `SIGHUP`, as described in the previous section.

The code of the three methods described above is listed in Listing 5-2. Commands for generating debug output and some comments have been removed for reasons of brevity.

```
unsigned long SleResources::saveSwitchDbgLevel;

/** Initialise saveSwitchDbgLevel variable according to the
 *  debug level specified on the command line (dbgLevel).
 */
void SleResources::end(int &argc, char *argv[]) {
  DrvRsrce::end(argc,argv);
  if (Resources::getDbgLevel())
    SleResources::saveSwitchDbgLevel = 0;
  else
    SleResources::saveSwitchDbgLevel = Resources::getDbgLevel();
}

/** Set the specified debug level.
 *  @param level debug level to be set (integer >= 0)
 */
static void SleResources::setDbgLevel(unsigned long level) {
  if (level > 0)
    Resources::dbgLevel = level;
  else
    Resources::dbgLevel = 0;
}

/** Toggle debugging on/off */
static void SleResources:: switchDbgLevel () {
  unsigned long oldLevel = Resources::dbgLevel;
  setDbgLevel (SleResources::saveSwitchDbgLevel);
  SleResources::saveSwitchDbgLevel = oldLevel;
}
```

Listing 5-2 Implementation of the switchDbgLevel method (SleResources class).

5.2.2.3 SleMapper

As the name implies, the *SleMapper* class performs the mapping (1) between PVSS DP identifiers and peripheral addresses (*PeriphAddr*) and (2) between peripheral addresses and

SL-Equip Hardware Objects (*SleMapObj*). As specified in 4.2.3.1.3, its most essential task is to add/remove peripheral addresses to/from the internal lists managed by the *HWMapper* super class. This task is performed by the `addDpPa()` and `clrDpPa()` methods with the interfaces listed below:

```
PVSSboolean SleMapper::addDpPa(DpIdentifier &dpId, PeriphAddr *confPtr)
PVSSboolean SleMapper::clrDpPa(DpIdentifier &dpId, PeriphAddr *confPtr)
```

The `clrDpPa()` method tries to find the hardware object (*SleMapObj*) corresponding to the peripheral address it receives as a parameter by means of a tool function provided by the base class. If such an object is found, it is removed from the internal list of hardware objects by means of a call to the `clrHWObject()` of the *HWMapper* class. Subsequently, the `clrDpPa()` method of the base class is called in order to remove the peripheral address from the internal list as well.

The `addDpPa()` method is fairly more complicated; its code is listed in Listing 5-3. First of all, an appropriate *Transformation* has to be assigned to the *PeriphAddr* object received as a parameter. The *Transformation* subclass to be instantiated is determined in accordance with the transformation type of the peripheral address, which was specified by the user during the configuration of the *_address* config (see 4.2.3.1.3). The fully configured *PeriphAddr* object is then added to an internal list by a call to the `addDpPa` method of the super class. If this operation succeeds, a new *SleMapObj* is created and filled with information contained in the peripheral address (address string, transformation type, data length etc.). The fully configured hardware object is also added to an internal list by a call to the `addHWObject()` method provided by the super class. If all described steps are successful, `PVSS_TRUE` is returned, otherwise the method returns `PVSS_FALSE`.

```
PVSSboolean  SleMapper::addDpPa(DpIdentifier &dpId, PeriphAddr
*confPtr) {
  // Set the appropriate transformation type for the config
  switch (confPtr->getTransformationType())
  {
    case SleTransIntType  :
      confPtr->setTransform(new SleTransInt); break;
    case SleTransStringType  :
      confPtr->setTransform(new SleTransString); break;
    case SleTransFloatType  :
      confPtr->setTransform(new SleTransFloat); break;
    default :
      // Error handling for types that are not handled by the driver
      ErrHdl::error(
        ErrClass::PRIO_SEVERE,        // Severe error
        ErrClass::ERR_PARAM,          // It was a wrong type
        ErrClass::UNEXPECTEDSTATE,    // Never expect
        "SleMapper", "addDpPa",       // Class and method
        CharString("Illegal transformation type ") +
        CharString( (int) confPtr->getTransformationType())
      );
      if (!confPtr->getName)
        return PVSS_FALSE;
      confPtr->setTransform(new Transformation());
      // Although there was an error add the config to the list
      // but don't create a HWObject for it.
```

```
      return HWMapper::addDpPa(dpId, confPtr);
  }
  // Call the addDpPa method of the super class, which adds the fully
  // configured PeriphAddr object to its internal list.
  if (!HWMapper::addDpPa(dpId, confPtr))
    return PVSS_FALSE;

  // Create a new SleMapObj for the given PeriphAddr.
  SleMapObj* objPtr= new SleMapObj(confPtr);
  // Set address and subindex appropriately
  objPtr->setAddress(confPtr->getName());
  objPtr->setSubindex(confPtr->getSubindex());
  objPtr->setType(confPtr->getTransform()->isA());
  objPtr->setDlen(confPtr->getTransform()->itemSize());
  // add the new SleMapObj to the list
  addHWObject(objPtr);

  return PVSS_TRUE;
} // addDpPa
```

Listing 5-3 Implementation of the addDpPa method (SleMapper class)

The implementation of the `actualize()` method is very similar to that of `addDpPa()`. It is called if a change in the peripheral address is triggered by the hardware, which will never be the case for the SL-Equip driver.

5.2.2.4 SleMapObj

The *SleMapObj* class was implemented following its specification in 4.2.3.3.1. As it mainly consists of `setXXX()` and `getXXX()` methods for reading and writing the different components of an SL-Equip address (specified in 2.3.2 and 4.2.2), we will not treat it in more detail here.

5.2.2.5 SleSrvHdl

As specified in 4.2.3.1.2, the SL-Equip Service Handler (*SleSrvHdl*) class handles read and write requests to the SL-Equip middleware. The `singleQuery()` and `writeData()` methods – the final links in the data acquisition and command chain of the driver – had to be overwritten for this purpose.

The framework calls the `singleQuery()` method whenever the value of a peripheral address needs to be polled from SL-Equip (e. g. when the polling time for a particular DPE has been reached). The peripheral address of the DPE to be retrieved is packed into a *HWObject* by the framework and then passed to the `singleQuery()` method as an input parameter. The `singleQuery()` method first finds the *SleMapObj* corresponding to the *HWObject* received from the *SleMapper*'s internal list. The SL-Equip address information contained in this object is then extracted and some SL-Equip variables (name of equipment host, timeout etc.) are set. The address information is packed into an SL-Equip client call (`EQUIP()` function) that is supposed to acquire the desired value from the hardware. If the client call is successful, the received data is packed into a new *SleMapObj* and communicated to PVSS via a call to the `toDp()` method of the *SleDriver* class. In return, the *SleDriver* calls the `toVar()` method of the *Transformation* object associated with the *SleMapObj* and finally communicates the new value to the Event Manager. If the client call fails and SL-Equip returns an error code, the error number is converted into a binary representation and the status bits of the *SleMapObj* are set accordingly. Also in this case, the `toDp()` method is invoked in order to communicate the error information to the Event Manager and, as a consequence, to the user.

The `writeData()` method does exactly the opposite of `singleQuery()`, writing changed values to SL-Equip and transmitting them to the equipment in the field. The logic implemented in the function is still very similar, as the `EQUIP()` function provided by the SL-Equip API works in both directions, for sending as well as receiving data. Naturally, no value is transmitted to PVSS as a result of the action.

The C++ code for the `singleQuery()` and `writeData()` methods is listed in Appendix B.

5.2.2.6 SleTransXXX

Derived from the general *Transformation* class provided by the PVSS API, the *SleTransXXX* classes are used for any transformation from SL-Equip values to PVSS DPE values and vice versa. The functionality of these classes' methods is specified in chapter 4.2.3.2. We take *SleTransFloat* as an example to describe the implementation of a transformation; *SleTransInt* and *SleTransString* have been implemented analogously.

The `itemSize()` method returns the size in bytes of a single value of the type to be transformed. For *SleTransFloat* objects, the `itemSize()` method returns 8.

The `toPeriph()` method is used for converting data in the command direction. The driver framework writes the data to be transformed into a *Variable* object and passes it to the method as an input parameter, together with the length of the data and, eventually, a sub-index designating the position of the element within a dynamic array. Furthermore, the framework allocates a buffer in which the `toPeriph()` method is supposed to write the transformed value (output parameter). `toPeriph()` first checks if the type of the *Variable* object received is either `FLOAT_VAR` (for floating-point values) or `DYN_VAR` (for dynamic arrays). If the type is `FLOAT_VAR`, the value is directly copied into the right position of the output buffer, which is calculated from the sub-index and the `itemSize` `(buffer + subindex * itemsize())`. If the variable type is `DYN_VAR`, each of the array's elements has to be processed separately. All elements (which are expected to be of type `FLOAT_VAR`) are extracted and transformed in recursive calls to `toPeriph()`. The method returns `PVSS_TRUE` if the transformation is successful.

```
PVSSboolean SleTransFloat::toPeriph(PVSSchar *buffer, PVSSuint len ,
  const Variable &var, const PVSSuint subix) const

{
  // Be paranoiac, check variable type
  if (var.isDynVar()) {
    const Variable *varPtr = 0;
    int  i = 0;
    for (varPtr = ((const DynVar &) var).getFirstVar();
         varPtr = ((const DynVar &) var).getNextVar(); i++) {
      // call yourself recursively
      if (! toPeriph(buffer, len, *varPtr, subix+i))
        return PVSS_FALSE;
    } // for
  } // if
  // Single float (in reality: double) value
  else if (var.isA() == FLOAT_VAR) {
    // Check if subindex and data length (len) match → avoid
    // overwriting the end of the buffer
    if ( len > subix * itemSize() ) {
      double d = ((FloatVar&) var).getValue();
```

```
      memcpy( &buffer[subix * itemSize()], &d, itemSize() );
    } // if
    else {
      // Data length was incorrect
      ErrHdl::error(
        ErrClass::PRIO_SEVERE,              // Data will be lost
        ErrClass::ERR_PARAM,                // Wrong parameterisation
        ErrClass::UNEXPECTEDSTATE,          // Never expect
        "SleTransFloat", "toPeriph",        // File and function name
        "Wrong variable length for data"    // don't know DP
      );
      return PVSS_FALSE;
    } // else
  } // else
  else {
    ErrHdl::error(
      ErrClass::PRIO_SEVERE,              // Data will be lost
      ErrClass::ERR_PARAM,                // Wrong parametrization
      ErrClass::UNEXPECTEDSTATE,
      "SleTransFloat", "toPeriph",        // File and function name
      "Wrong variable type for data"      // don't know DP
    );
    return PVSS_FALSE;
  } // else
  // Everything OK
  return PVSS_TRUE;
}
```

Listing 5-4 Implementation of the toPeriph method (SleTransFloat class)

The `toVar()` method is used for transforming values obtained from SL-Equip to PVSS variables; it is thus the counterpart to the `toPeriph()` method. A buffer containing the data to be transformed, the size of the buffer and a sub-index are passed to the method as input parameters. First, it has to be ensured that the given sub-index, multiplied by `itemSize()`, does not exceed the size of the input buffer, which would inevitably lead to an exception. If the input parameters are correct, the value is copied into a *FloatVar* variable which is then returned to the caller. If the input parameters are incorrect, the method returns `NULL`.

Finally, the `isA()` method returns the *TransformationType* represented by the class, i. e. `SleTransFloatType`.

As mentioned above, the implementation of *SleTransInt* and *SleTransString* is very similar, apart from the fact that *SleTransString* does not support dynamic arrays. Contrary to floats or integers, the length of a string (i. e. its `itemSize()`) cannot be determined in advance.

5.2.3 Implementation of the Driver Configuration Panel

In order to configure the DPEs to be retrieved by the SL-Equip driver conveniently via the PVSS user interface, a new panel had to be created. Thanks to a PVSS naming convention, this panel is integrated into the PVSS parameterisation module and displayed as soon as the *_address* config of a DPE connected to the SL-Equip driver is modified.

A screenshot of the panel implemented for the SL-Equip driver is shown in Figure 5-2. The left part of the screenshot shows the DP hierarchy browser of the PVSS PARA module while the right part shows the parameterisation panel described in this section. In the left upper part of the panel, SL-Equip address information (consisting of family, member, host action and user option) is entered. The host and user option fields are optional. In the right upper part, polling start time, polling interval and request timeout in seconds are configured. In the lower part of the panel, the number of the driver to which the DPE shall be connected, the input/output direction and the SL-Equip mode (~ data type in SL-Equip) are specified.

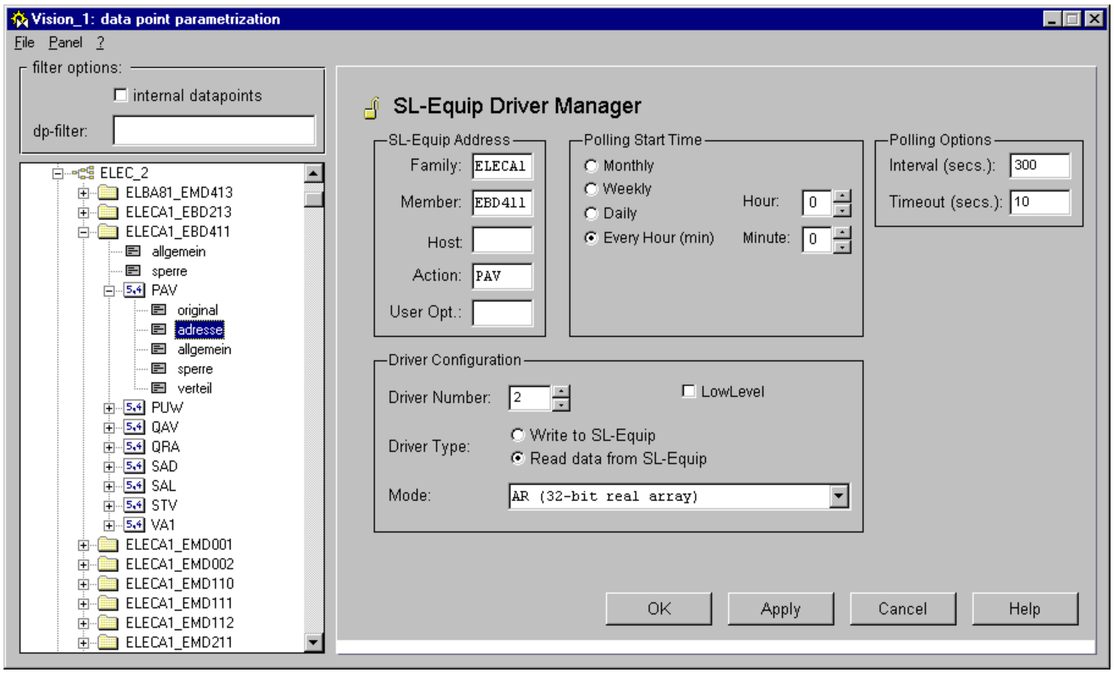


Figure 5-2 Screenshot of the parameterisation panel for the SL-Equip driver

An initialisation script is executed whenever the panel is displayed. It calls a library function that reads out the configs attached to the current DPE and fills the GUI elements with appropriate values. Subsequently, the user can modify these values conveniently via the panel and save them by clicking on the OK or Apply button. Clicking on one of these buttons also triggers the execution of a script that processes the information contained in the GUI elements and saves them to the appropriate configs of the DPE concerned. The PVSS run-time system then takes care of transmitting the changed values to the Event Manager, which forwards them to the Database Manager and the SL-Equip Driver Manager. As soon as the driver has received the changes, it applies them to its internal lists (*SleMapper* class).

This panel will only be used for configuration purposes once the system has become operational, for the initial driver configuration is generated automatically from information stored in the TDRefDB (see chapter 4.3). Even so, it will serve as a practical means for testing whether the configuration information was imported correctly and for experimenting with parameters as the polling interval or the different timeouts.

5.3 Implementation of the Static Configuration Database

This section focuses on the implementation of the static configuration database. First of all, the implementation of the TDRefDB database structure specified in 4.3.1 is presented. After that, the code of the scripts for importing data into this structure is explained. Finally, the data loading SQL script for extracting data from the TDRefDB and generating ASCII Manager-compatible text files is explicated.

5.3.1 TDRefDB Database Structure

For the implementation of the TDRefDB structure described in chapter 4.3.1 (*Database Design*), the creation of the tables containing the data (4.3.1.2) and the creation of the user views (4.3.1.3) have to be distinguished.

5.3.1.1 TDRefDB Tables

The TDRefDB table structure was *generated automatically* from the server model diagram depicted in Figure 4-8. The diagram was created using Oracle Designer® 2000, a powerful CASE tool for database design that supports the automatic generation of database schemata from so-called server models. A re-engineering option, called *design capturing*, allows the generation of server model diagrams from existing database structures. This inverse approach was chosen for creating the server model diagram of the user views described in the ensuing section.

5.3.1.2 TDRefDB User Views

The user views depicted in Figure 4-9 were created manually, by means of an SQL script. The SELECT statements for assembling the data contained in the views are rather complex, including multiple joins, subqueries and meta columns. This is why tool-supported generation would not have facilitated the task of view creation. So, only the reverse-engineering option of Designer 2000 was used to create the server model diagram depicted in Figure 4-9.

We illustrate the view creation process by means of an example, the `VPVSS_DPT` and `VPVSS_DPE` views. As mentioned in 4.3.1.3, DPTs are declared in `VPSS_DPT` and their hierarchical structure of DPEs is defined in `PVSS_DPE`. The SELECT statements used for creating the views are listed in Listing 5-5.

```
CREATE OR REPLACE VIEW vpvss_dpt AS
  SELECT dpt_name, dpt_type, dpt_comment
  FROM pvss_dpt
  ORDER BY dpt_name;

CREATE OR REPLACE VIEW VPVSS_DPE(
  dpt_name, dpe_level, dpe_name, dpe_type, dpe_reftype
)
AS SELECT
    dpt.dpt_name, dpe_level, dpe_name, dpe_type, dpt2.dpt_name
  FROM (
    -- hierarchical subquery as one of the data sources
    SELECT dpe_dpt_id, dpe_id, level dpe_level, dpe_name, dpe_type
      FROM pvss_dpe
      START WITH dpe_id IN (
              SELECT dpe_id FROM pvss_dpe WHERE dpe_parent IS NULL )
      CONNECT BY PRIOR dpe_id = dpe_parent
    ) dpe,
    pvss_dpt dpt,
    pvss_dpe_typeref dpet,
    pvss_dpt dpt2
  WHERE
    dpt.dpt_id = dpe.dpe_dpt_id  AND
    dpe.dpe_id = dpet.dpet_dpe_id (+) AND
    dpet.dpet_dpt_ref = dpt2.dpt_id (+)
  ORDER BY dpt_name;
```

Listing 5-5 Statements for creating the VPVSS_DPT and VPVSS_DPE views (SQL)

The statement for creating the VPVSS_DPT view only selects three columns of the PVSS_DPT table and sorts the results by dpt_name.

The definition of the VPVSS_DPE view is far more complex. First of all, it contains data from four different sources:

- PVSS_DPT is used twice: once for selecting the name of the DPT associated with the DPE described by the record and once for selecting the name of a DPT that could eventually be referenced the DPE.
- PVSS_DPE_TYPEREF is used to find the identifier of DPTs that are referenced by one or more DPEs.
- A hierarchical subquery presents the columns of PVSS_DPE in a different format and includes the level of hierarchy for each DPE.

These four sources require the definition of three join criteria:

- PVSS_DPT (dpt1 in the statement above) and PVSS_DPE are joined by an inner join on the DPT identifier.
- PVSS_DPE and PVSS_DPE_TYPREF are joined by a right outer join on the DPE identifier.
- PVSS_DPE_TYPREF and PVSS_DPT (dpt2 in the statement above) are joined by a right outer join on the identifier of the referenced DPT.

Finally, the returned records are ordered by dpt_name.

We illustrate the abstract description given above by an example, falling back on our sample DPT TypeA, defined in section 4.3.1.2.2. A query for all elements of TypeA would return the following result:

DPT_NAME	DPE_LEVEL	DPE_NAME	DPE_TYPE	DPE_TYPREFF
'TypeA'	1	'aFloat'	22	NULL
'TypeA'	1	'aDFloat'	6	NULL
'TypeA'	1	'aStruct'	1	NULL
'TypeA'	2	'anInt'	21	NULL
'TypeA'	2	'aBool	23	NULL

Table 5-1 Example of a DPT definition in VPVSS_DPE

The SQL statements for creating the remaining four views (VPVSS_DP, VPVSS_ADDRESS, VPVSS_DISTRIB and VPVSS_DPE_COMMENT) are not discussed in detail.

5.3.2 Import of Existing Configuration Information in the TDRefDB

This section describes the implementation of the data import scripts and procedures specified in chapter 4.3.2.3. First, the implementation of the PL/SQL procedures for importing TDS configuration information is explained. Thereafter, the implementation of the Perl scripts for importing the contents of SL-Equip configuration files is dealt with.

5.3.2.1 Implementation of PL/SQL Procedures for Importing TDS Configuration Data

This section describes the implementation of the import strategy for static TDS configuration data as specified in chapter 4.3.2. As mentioned above, PL/SQL, Oracle's *procedural* *language (PL) superset of the structured query language* (SQL) [Koch and Loney, 1997], was used for the implementation. The following four procedures have been implemented and grouped together in a PL/SQL package named `PVSS`:

(1) `Import_DPT` (for importing DPTs and their subordinated DPEs),
(2) `Import_DP` (for importing DP declarations),
(3) `Import_Comment` (for filling the `PVSS_DPE_COMMENT` table) and
(4) `Import_Address` (for filling the `PVSS_ADDRESS` table).

The four procedures have to be executed in the order in which they are listed above (though (3) and (4) can be exchanged), respecting their mutual dependencies. As the import strategy for each of the TDRefDB tables has been described in a very detailed manner in chapter 4, we only pick out one of the procedures (`Import_DPT`) that serves an example for the discussion of implementation-specific issues. The other procedures are very similar in functioning and logic.

Oracle Stored Procedures usually consist of three parts:

(1) a *declarative section* in which all variables, constants and cursors used in the procedure must be declared,
(2) an *instruction section* consisting of a series of procedural language constructs and SQL statements and
(3) an optional *exception handler* section in which errors occurring during the procedure's execution are handled.

We start with the `Import_DPT` procedure's declarative section. In addition to several constants representing PVSS DPE types (`DPEL_FLOAT`, `DPEL_INT`, `DPEL_STRUCT` etc.) and some auxiliary variables, the procedure declares two explicit cursors[4] for selecting the data to be processed from the `VPTS_PVSS` view (see 4.3.2.2.1, Figure 4-11). The first cursor (`dpt_cursor`) retrieves a list of distinct DPT names to be declared in the `PVSS_DPT` table; the second one (`dpe_cursor`) retrieves a list of distinct DPE names and address modes for a specific DPT specified as a cursor parameter.

The instruction section of the `Import_DPT` procedure is implemented as follows:

(1) The cursor containing the names of the DPTs to be created is opened.
(2) For each row fetched from the cursor:
   (a) A new `PVSS_DPT` record is created. The element type for the DPT is `DPEL_STRUCT` by default, for all DPTs have subordinated elements and are thus represented by structures in PVSS.
   (b) A list of DPE for the DPT is obtained by means of the `dpe_cursor`. For each row fetched from this second cursor, one record in the `PVSS_DPE` table is created. If the address mode is 'I', the element type is derived from the attribute's name; if the address mode is 'O', the element type is `DPEL_STRUCT` and three subordinated (child) `PVSS_DPE` records are created. These three dependent

[4] Cursors are PL/SQL constructs representing named work areas for the execution of SQL statements and for storing processing information ([Oracle, 1997]). They are particularly useful when a query returns multiple rows that need to be processed one by one.

records represent the elements of a special TDS command structure consisting of a TagName, a ReportCode and a ReportMessage. This command structure is used for all TDS DPEs in the command direction.

(c) The current transaction is committed.

(3) An auxiliary procedure that automatically fills in the `dpe_full_name` column of the `PVSS_DPE` table is called.

(4) The current transaction is committed.

The current implementation of the `Import_DPT` procedure does not have an exception handling section. The (simplified) code is listed below.

```
PACKAGE BODY PVSS IS
  PROCEDURE IMPORT_DPT IS
    -- auxiliary constant values
    dpel_struct CONSTANT NUMBER(2):= 1;
    dpel_float CONSTANT NUMBER(2):= 22;
    dpel_int CONSTANT NUMBER(2):= 21;
    dpel_bool CONSTANT NUMBER(2):= 23;
    dpel_string CONSTANT NUMBER(2):= 25;
    dpel_typeref CONSTANT NUMBER(2):= 41;

    v_dpt_id NUMBER(9);            -- DPT identifier
    v_command_dpt_id NUMBER(9);    -- Identifier of the Command DPT
    v_dpe_id NUMBER(9);            -- DPE identifier
    v_dpe_type NUMBER(2);          -- DPE type identifier

    CURSOR dpt_cursor IS
      SELECT DISTINCT dptname dpt_name
      FROM VPTS_PVSS
      ORDER BY dpt_name;

    CURSOR dpe_cursor (p_dpt_name IN VARCHAR2) IS
      SELECT DISTINCT
        dptname dpt_name,
        attrname dpe_name,
        addrmode dpe_mode
      FROM VPTS_PVSS
      WHERE dptname = p_dpt_name
      ORDER BY attrname;

  BEGIN
    ------------------------------------------------------
    -- Create DPT and DPE records
    ------------------------------------------------------
    FOR dpt IN dpt_cursor LOOP
      INSERT INTO PVSS_DPT VALUES (
        dpt_id.nextval, dpt.dpt_name,
        dpel_struct, 'TDS Data Point Type'
      );
      FOR dpe IN dpe_cursor(dpt.dpt_name) LOOP
        -- Get ID for existing DPT
        IF dpe.dpe_mode = 'I' THEN
          IF UPPER(SUBSTR(dpe.dpe_name, 2, 1)) = 'M' OR
             UPPER(SUBSTR(dpe.dpe_name, 2, 1)) = 'L' THEN
            v_dpe_type := dpel_float;
          ELSE
            v_dpe_type:= dpel_bool;
          END IF;
```

```
        ELSE
          v_dpe_type:= dpel_struct;
        END IF;
        SELECT dpe_id.nextval INTO v_dpe_id FROM dual;
        INSERT INTO PVSS_DPE VALUES (
          v_dpe_id, dpt_id.currval, dpe.dpe_name,
          v_dpe_type, NULL, NULL
        );
        IF dpe.dpe_mode = 'O' THEN
          -- Explicitly create instances of the command type's DPEs
          INSERT INTO PVSS_DPE VALUES (
            dpe_id.nextval, dpt_id.currval, 'TagName',
            dpel_string, v_dpe_id, NULL
          );
          INSERT INTO PVSS_DPE VALUES (
            dpe_id.nextval, dpt_id.currval, 'ReportCode',
            dpel_int, v_dpe_id, NULL
          );
          INSERT INTO PVSS_DPE VALUES (
            dpe_id.nextval, dpt_id.currval, 'ReportMessage',
            dpel_string, v_dpe_id, NULL);
        END IF;
      END LOOP;
      COMMIT;
    END LOOP;
    -- Call the Update_DPE procedure to generate the full names
    -- of the DPEs
    Update_DPE;
    COMMIT;
  END Import_DPT;

  . . . other procedures . . .

END PVSS;
```

Listing 5-6 Implementation of the Import_DPT procedure (PL/SQL)

5.3.2.2 Implementation of Perl Scripts for Importing SL-Equip Configuration Data

As specified in section 4.3.2.3, SL-Equip configuration data was extracted from existing ASCII files and inserted in the TDRefDB by means of Perl scripts. These scripts are described in the present section.

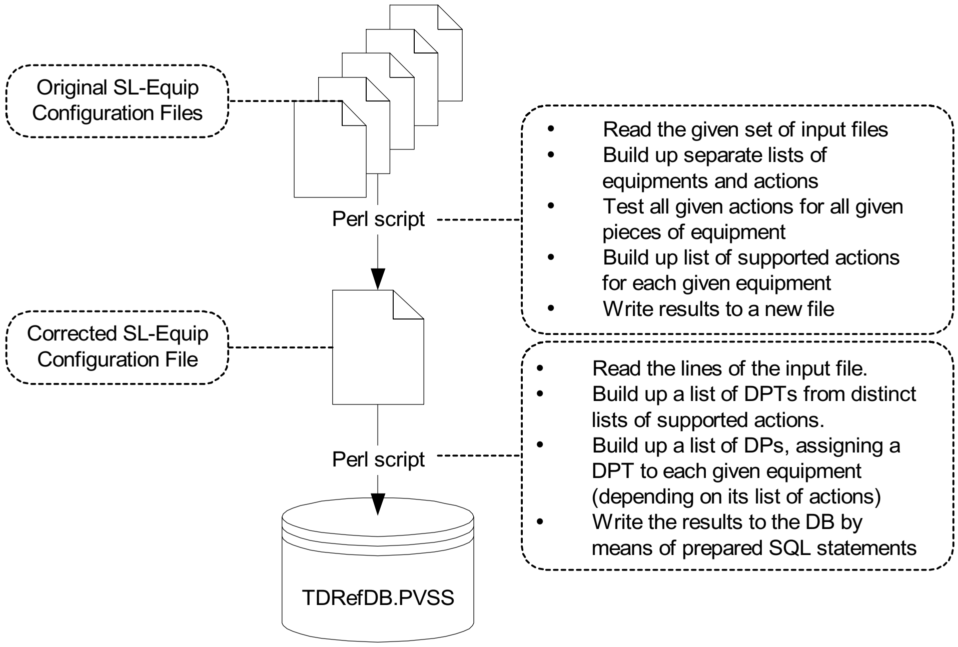


Figure 5-3 Import of SL-Equip configuration data

As shown in Figure 5-3 and explained in 4.3.2.3, two scripts had to be implemented: one for validating and correcting existing configuration data and one for inserting the corrected information in the TDRefDB.

5.3.2.2.1 Validation and Correction of the given information

The first Perl script has to read and merge the information contained in a given set of input files. This only requires a few file and pattern matching operations that are rather easy to implement in Perl. When looking for a strategy to validate the given information, however, the task becomes more delicate. Two questions have to be answered:

(a) How can it be checked whether a given piece of equipment supports a given action?
(b) How can it be discovered whether a given piece of equipment supports any other actions?

As far as question (a) is concerned, the answer is fairly simple: The equipment has to be "asked" by means of an SL-Equip client implemented in C/C++. If SL-Equip does not return an error code (e.g. 66 for "equipment not found" or 36 for "invalid action"), we conclude that the equipment supports the given action.

Question (b) is more challenging. Theoretically, we would have to test all possible actions (i.e. all 26^3 three-letter combinations) for all given pieces of equipment. In practice, this is neither feasible nor sensible. We will thus proceed as follows:

(1) Equipment name and action are separated. Consequently, we obtain one list containing the identifiers of all pieces of equipment and one list containing all actions associated with ANY equipment.
(2) Each of the actions on the action list is tested for all equipment on the equipment list.
(3) As a result, a map (i. e. an associative array) of supported actions for each given piece of equipment is built up and written to the output file.

This procedure does not guarantee that all supported actions for a given piece of equipment will be found, for there could be actions that are not mentioned in any of the configuration files. Hence, they would never be tested. For this reason, a manual check of the results by the persons responsible for the equipment would be desirable.

The code of the Perl script for validating the input files is listed in Appendix C.

5.3.2.2.2 Insertion in the TDRefDB

The second Perl script takes the corrected SL-Equip configuration file produced by the script described in the previous section as input. It reads the data contained in the file and processes it in a way that PVSS DPTs, DPs and *_address* configs can be extracted and entered in the TDRefDB.

We illustrate this processing by means of an example. Let us assume that the following configuration file (which is extracted from a real configuration file) is given:

```
EMD002/A2  ELECA2_EMD002 --- --- --- VSN
EBD213/A2  ELECA2_EBD213 STV SAL SAD ---
EME200/A2  ELECA2_EME200 --- --- --- VSN
EMD212/A2  ELECA2_EMD212 STV SAL SAD ---
EBE215/A2  ELECA2_EBE215 --- --- --- VSN
EMD213/A2  ELECA2_EMD213 STV SAL SAD ---
```

Listing 5-7 Example of a corrected SL-Equip configuration file

First of all, the script has to define DPTs for groups of equipment supporting the same list of actions. The DPTs are automatically named `ELEC1` to `ELECn` since the information contained in SL-Equip configuration files mainly concerns electrical equipment.

For the example above, two different DPTs would be defined:

- `ELEC1`: supporting one single action called `VSN` and
- `ELEC2`: supporting the actions `SAD`, `SAL` and `STV` (in alphabetical order).

In a second step, DPs corresponding to equipment names are defined and assigned a suitable DPT. For the example above, six DPs would be defined:

- `ELECA2_EMD002` of type `ELEC1`
- `ELECA2_EME200` of type `ELEC1`
- `ELECA2_EBE215` of type `ELEC1`
- `ELECA2_EBD213` of type `ELEC2`
- `ELECA2_EMD212` of type `ELEC2`
- `ELECA2_EMD213` of type `ELEC2`

Finally, *_address* configs have to be generated from the given information. All fields of the _address config are filled with real or default values, following the rules for PVSS address mapping defined in chapter 4.2.2.

As soon as all the required information is defined, it is written to the database by means of the Perl Database Interface (DBI) package. This object-oriented package allows the creation of prepared SQL statements and their consecutive execution. The code of this second Perl script is equally listed in Appendix C.

5.3.3 Implementation of an SQL Script for Exporting PVSS Configuration Data

This section deals with the SQL script for extracting PVSS configuration information from the TDRefDB. The requirements for the script have been specified in chapter 4.3.3.

The script is divided in two parts:

(1) A series of commands *configures the SQL*PLUS environment* and the script's output format.
(2) A succession of SQL statements *extracts PVSS configuration information* from the database and writes it to an output file.

The commands in the first part of the script mainly assign values to SQL*PLUS environment variables (see [Oracle, 1997]) with the intention of formatting the script's output in a way that it can directly be spooled to a text file. For this purpose, all SQL*PLUS options that could unintentionally re-format the queries' output (e. g. command echoing, column headings, line wrapping, automatic page breaks etc.) are turned off. Furthermore, the output of the script is redirected to a text file instead of being displayed on the screen (`SPOOL` command).

The `SELECT` statements in the second part of the script extract information from the TDRefDB user views. The data is formatted in a way that the results are printed in an ASCII Manager-compatible format (see section 4.3.3.1):

ASCII Manager files are divided in sections, where each new section must start with a header line "declaring" the PVSS attributes represented by the columns of the following section. As SQL*PLUS does not support simple "print" commands, the sections' headers had to be selected from Oracle's DUAL table (e.g. "`SELECT 'test' FROM DUAL;`" would simply print "test" to the output file). The sections' bodies are created by means of SQL queries accessing the user views described in chapter 4.3.1.3. These statements select the information required from the database and concatenate the columns retrieved in a way that the output can be read by the PVSS ASCII Manager. (e.g. "`SELECT DPT_NAME ||' '|| DPT_TYPE FROM VPVSS_DPT;`" would print 'TypeA 1' to the output file).

The complete code of the SQL script is listed in Appendix D. In order to execute the script, a connection to the Oracle database account containing the PVSS user views must be established. The script can then be executed by entering "`START filename.sql`" on the SQL*PLUS command line.

5.4 Implementation of the User Interface

To complete the implementation of the SPS Restart Application – from the data acquisition level up to the user interface level – this section explains how the application's user interface has been created. As mentioned in section 4.4, only one PVSS panel has been developed by the author, further panels will later be developed by TCR operators.

The sample panel created in the course of this thesis work is based on the functional diagram of SPS sextant 2 (BA2), which is displayed in Figure 4-13 of the previous chapter. BA2 contains a number of subsystems involved in the machine's start-up:

- 18 Kilovolt electricity,
- 400 Volt electricity,
- Vacuum,
- Demineralised water for cooling,
- Raw water (a primary water circuit feeding the demineralised water circuits
- etc.

Each of these subsystems had to be analysed in order to find out how the current state of the system (see Table 4-10) can be determined. For this purpose, existing applications displaying SPS equipment information have been analysed. Figure 5-4 displays a mimic diagram of such an application that is currently used in the TCR. The figure represents electrical installations in BA2: (1) the "18 Kilovolt stable" subsystem in the upper part of the diagram and (2) the 400 Volt stable subsystem in the lower part.

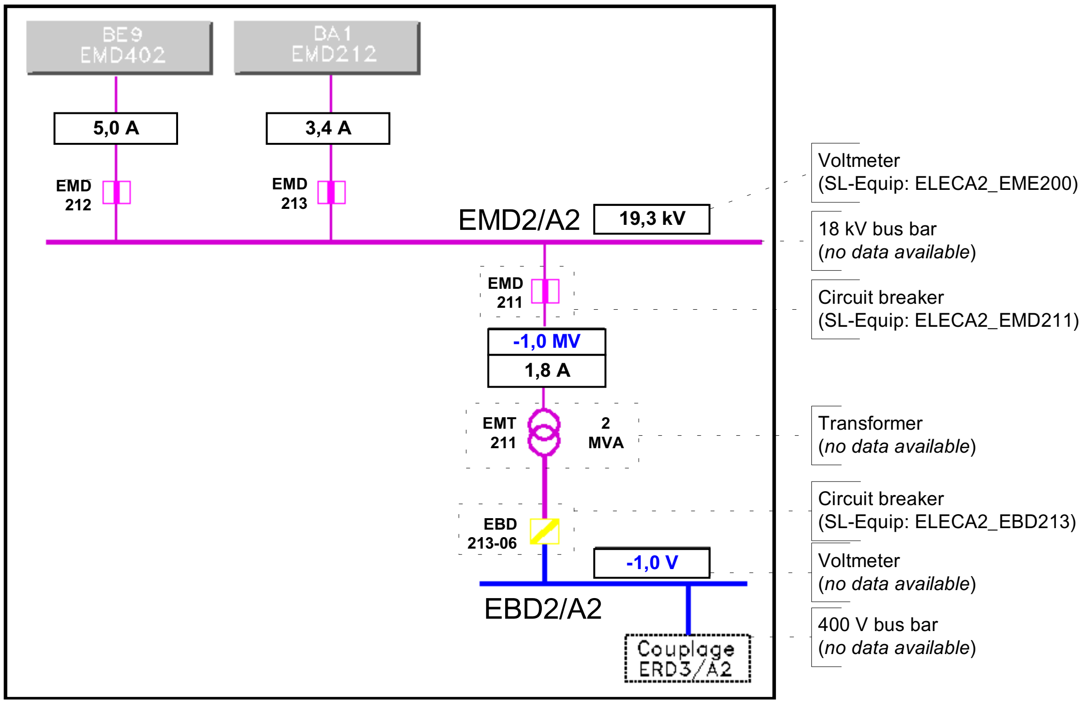


Figure 5-4 Screenshot of UMMI application

The diagram provides all the information we need to animate the corresponding boxes in our PVSS panel. We see that the "18 kV stable" subsystem is "`ST_OK`" if there is a voltage on the "18 kV bus bar" (purple line in the above diagram). This voltage is measured by a voltmeter labelled "EMD2/A2" and can be read out via SL-Equip. If there is no voltage (or a voltage much lower or higher than 18 kV), the "18 kV stable" subsystem shall be in "`ST_FAULT`" state.

A third state, "ST_INVALID", had to be introduced in order to indicate that the value of a piece of equipment could not be determined at run-time, due to a hardware, transmission or driver error.

The "400 Volt stable" subsystem is slightly more complicated as it depends on the voltage on the 18 kV bus bar. As the voltage on the 400 V bus bar cannot be read out directly (the voltmeter concerned is not connected to SL-Equip), three parameters have to be taken into account when determining the state of the 400 V bus bar:

(1) the voltage on the 18 kV bus bar must be OK (~ 18 kV),
(2) the circuit breaker "EMD 211" must be closed and
(3) the circuit breaker "EBD 213-06" must be closed.

All the information required for the "18 kV stable" and "400 V stable" subsystems is available via SL-Equip and can therefore be accessed from PVSS by means of the SL-Equip driver developed in the course of this thesis work. Information about the "vacuum" and "18 kV pulsed" subsystems is equally acquired via SL-Equip while "raw water" and "demineralised water" information is acquired via the TDS driver.

All other subsystems depicted in the Figure 4-13 are supervised and controlled by systems that are currently not accessible from PVSS. Consequently, the corresponding boxes in the PVSS panel could not be animated (ST_NOT_ANIMATED). For each of the subsystems mentioned above, a box in the PVSS mimic diagram had to be created. The resulting panel is shown in Figure 5-5. As it was mentioned in the design chapter, the panel looks very similar to the functional diagram of the BA, depicted in Figure 4-13.

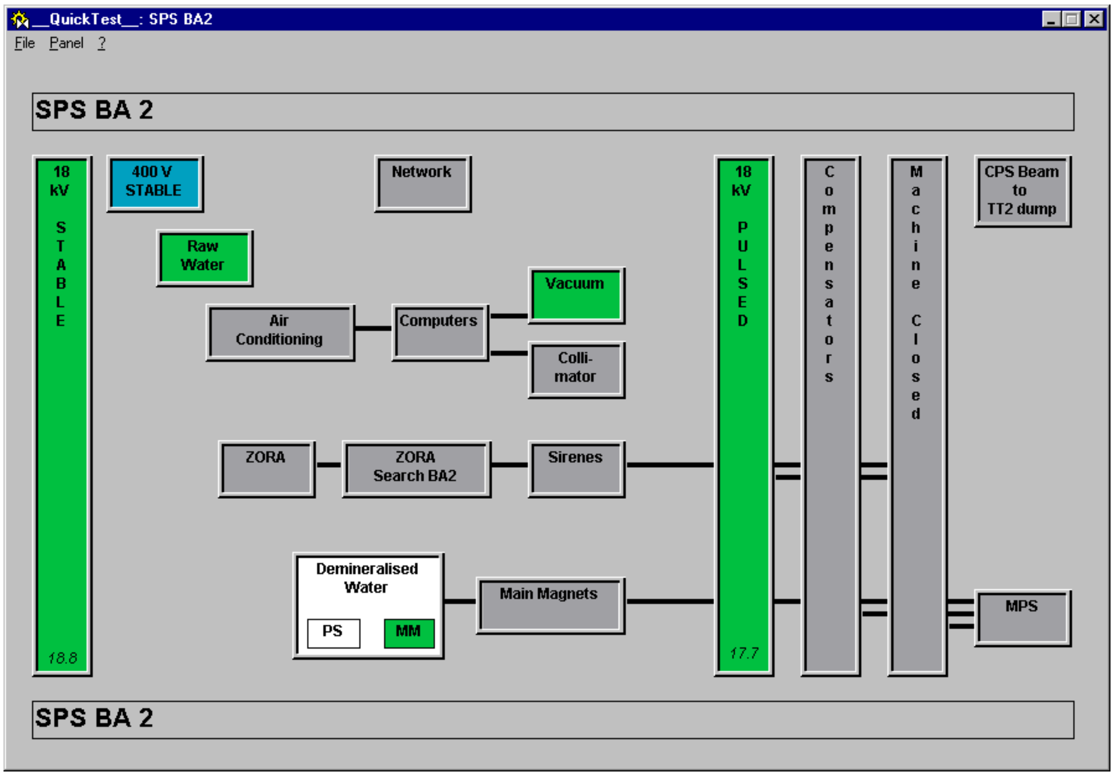


Figure 5-5 Screenshot of the PVSS panel for SPS BA2

The background colour of the boxes represents the current state of the subsystem concerned, following the colour conventions described in Table 4-10. How the background colour is changed at run-time whenever the state of one of the supervised systems changes, is explained in the following paragraph, taking the “400 V stable” box as an example.

The run-time behaviour of PVSS panels is implemented by means of CONTROL scripts that are executed whenever certain events (e.g. initialisation, mouse click etc.) occur. In order to change the background colour of our “400 V stable” box dynamically, depending on the values of the DPEs concerned, an “initialisation handler” had to be implemented. This function is executed as soon as the panel is initialised and connects to the DPEs concerned by registering a call-back function.

The call-back function is called by PVSS as soon as the value of one of the registered DPEs changes. It evaluates the new values and sets the background colour of the box accordingly. The code of the initialisation handler and the call-back function is listed in Listing 5-8.

```
main() {
  dpConnect("EP_setBackColorCB",
    //ELECA2_EBD213
    "st_tsi:ELECA2_EBD213.STV:_online.._value",
    "st_tsi:ELECA2_EBD213.STV:_online.._aut_inv",
    //ELECA2_EBMD211
    "st_tsi:ELECA2_EMD211.STV:_online.._value",
    "st_tsi:ELECA2_EMD211.STV:_online.._aut_inv",
    //ELECA2_EME200
    "st_tsi:ELECA2_EME200.VSN:_online.._value",
    "st_tsi:ELECA2_EME200.VSN:_online.._aut_inv"
  );
}

EP_setBackColorCB(
  string ebd213valStr, float ebd213,
  string ebd213invStr, float ebd213_invalid,
  string emd211valStr, float emd211,
  string emd211invStr, float emd211_invalid,
  string eme200valStr, float eme200,
  string eme200invStr, float eme200_invalid
) {
  if (ebd213_invalid || emd211_invalid || eme200_invalid) {
    this.backCol = "ST_INVALID";
  }
  else if (eme200 > 0 && ebd213 == 2  && emd211 == 2) {
    this.backCol = "ST_OK";
  }
  else if (ebd213 == 1 || emd211 == 1) {
    this.backCol = "ST_FAULT";
  }
  else {
    this.backCol = "ST_INVALID";
  }
}
```

Listing 5-8 PVSS Control Script embedded in a user interface panel

All other boxes have been animated in a similar way, using different DPEs.

The colour convention described in the previous chapter was implemented in PVSS by means of named colour constants. These colour constants have been applied to all user interface elements representing equipment/system states (as can be seen from Listing 5-8, for example). In addition, a "help" panel explaining the meaning of the different colours was created (see Figure 5-6).

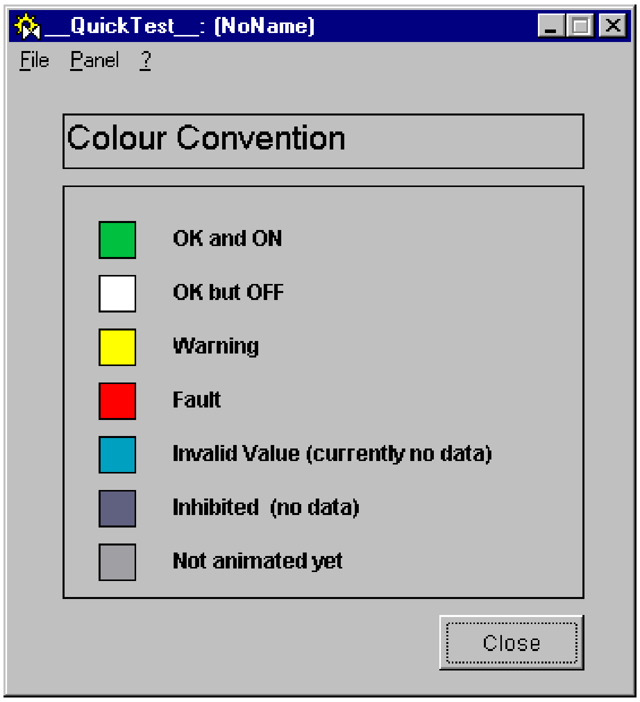


Figure 5-6 Screenshot of the colour convention panel

6. VALIDATION AND VERIFICATION

This chapter outlines the measures that were taken to test the different components of the SPS Restart Application as well as the system as a whole. Following [Sommerville, 1995], testing involves two different aspects:

(1) "*Do we build the right product?*" (validation)
It has to be ensured that the produced software system meets the needs of the customer.
(2) "*Do we build the product right?*" (verification)
It has to be checked whether the system conforms to its specification and produces the expected results.

[ESA BSSC, 1994] defines validation as the *evaluation of software at the end of the software development process to ensure compliance with the user requirements.* This definition sees validation as *end-to-end verification*, which means that checks whether the "right product" has been built are only done once the product has been finished. In the case of the SPS Restart Application, validation steps have been included in the software engineering process. In order to make sure that the proposed solution meets the users' requirements, the application has been developed in close co-operation with TCR operators. Informal reviews and early presentations of prototypes proved to be very constructive. Furthermore, the participation of future users in the development process assured that the users identified with the product and were thus satisfied with the final solution.

According to [ESA BSSC, 1994], the *verification aspect of testing* is supposed to show that (a) the product performs as specified and (b) the product does not contain defects that prevent it from performing as specified. Due to a lack of development time, verification has not been done in a very structured way. A series of white-box tests has been performed at the end of the implementation phase but there was not enough time to elaborate a structured test plan and to test the system in an exhaustive manner.

6.1 Component Tests

This section explains how each of the SPS Restart Application's components presented in this thesis work has been tested, starting with the PVSS system's set-up.

6.1.1 PVSS System Set-up

Two kinds of tests regarding the system's set-up (see section 5.1) were performed:

(1) *Redundancy tests* evaluating the general stability and robustness of the system.
(2) Distribution tests checking whether data exchange with external PVSS systems is possible.

As high dependability was one of the system's central design goals (see section 3.2.1.1), it had to be verified whether the system continues to work in case of a partial or complete breakdown of one of the two redundant servers. This redundancy test procedure was facilitated by the fact that PVSS provides a standard *redundancy overview panel* for displaying the current state of all the components making up a redundant PVSS system. This standard panel was slightly modified in order to reflect the particular configuration of the SPS

Restart Application (see Figure 6-1). The modified redundancy overview panel and the PVSS PARA module were then started on a Microsoft Windows NT 4.0 machine for test execution.

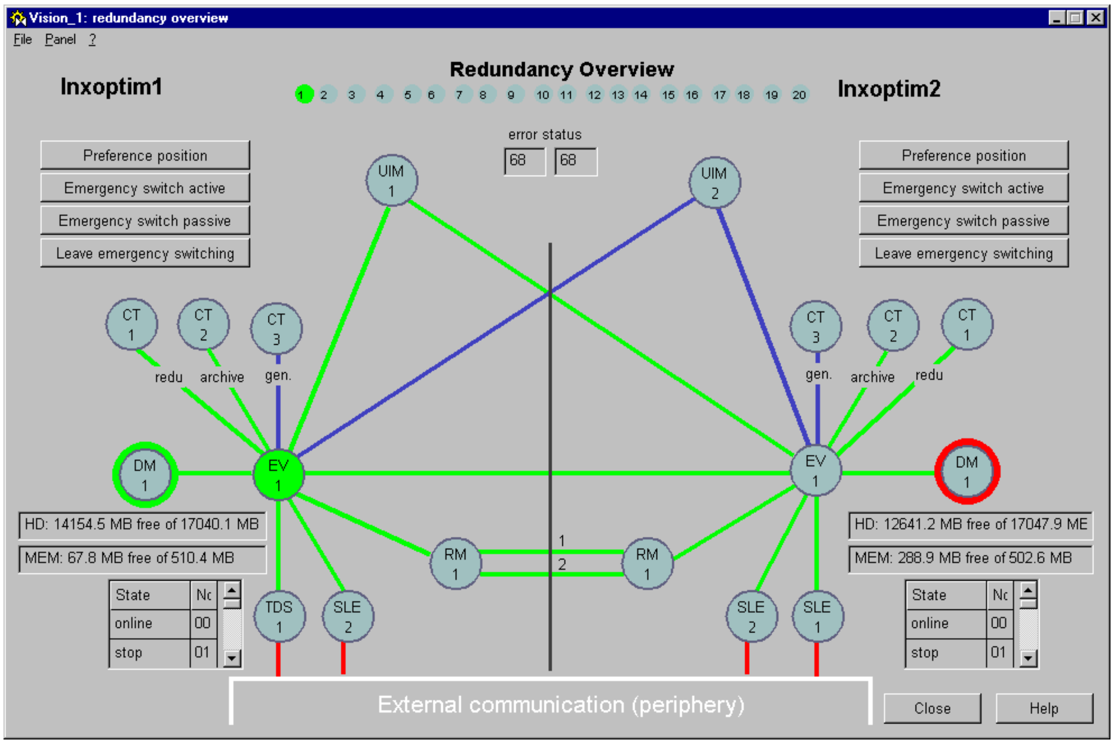


Figure 6-1 PVSS Redundancy overview panel (both servers up and running)

The following (non-exhaustive) list gives some examples of redundancy tests that have been performed:

- One of the redundant PVSS servers was switched off unexpectedly in order to simulate the breakdown of one of the two redundancy partners. The objective of this test case was to check whether the remaining server becomes active (as specified in [ETM, 2000]) and ensures the uninterrupted availability of the system. The test was successful; no data was lost.
- The primary network connection between the two PVSS servers was removed at run-time in order to check whether the system remains stable although no data can be exchanged (as the secondary network connection is used for the exchange of status information only). As expected, the system continued to work without interruption and no data was lost. When the network connection was re-established, the inactive PVSS system was restarted automatically in order to synchronise its database with the active one.
- The secondary network connection, i. e. the direct link between the two servers, was removed at run-time. In this case, status information was exchanged via the primary network connection and the system continued to operate normally.
- Selected tasks (managers) of the active system were killed in order to check if the other system (i. e. the system in a better condition) becomes active and ensures the system's operation. The test case was successful; the killed manager (in the case of the Event and Data Managers: the complete system) was restarted automatically and no data was lost.

As mentioned above, the *correct functioning of the distribution mechanism* had to be checked as well. For this purpose, a second (non-redundant) PVSS system was set up and configured for data exchange with the redundant system for the SPS Restart Application. Subsequently, a synoptic panel accessing data points (DPs) from both systems was created. The set-up for the distribution tests is shown in Figure 6-2. The test panel was executed on both systems in order to verify if the systems can mutually access their data points. All data was displayed correctly; we can thus conclude that the distribution mechanism works.

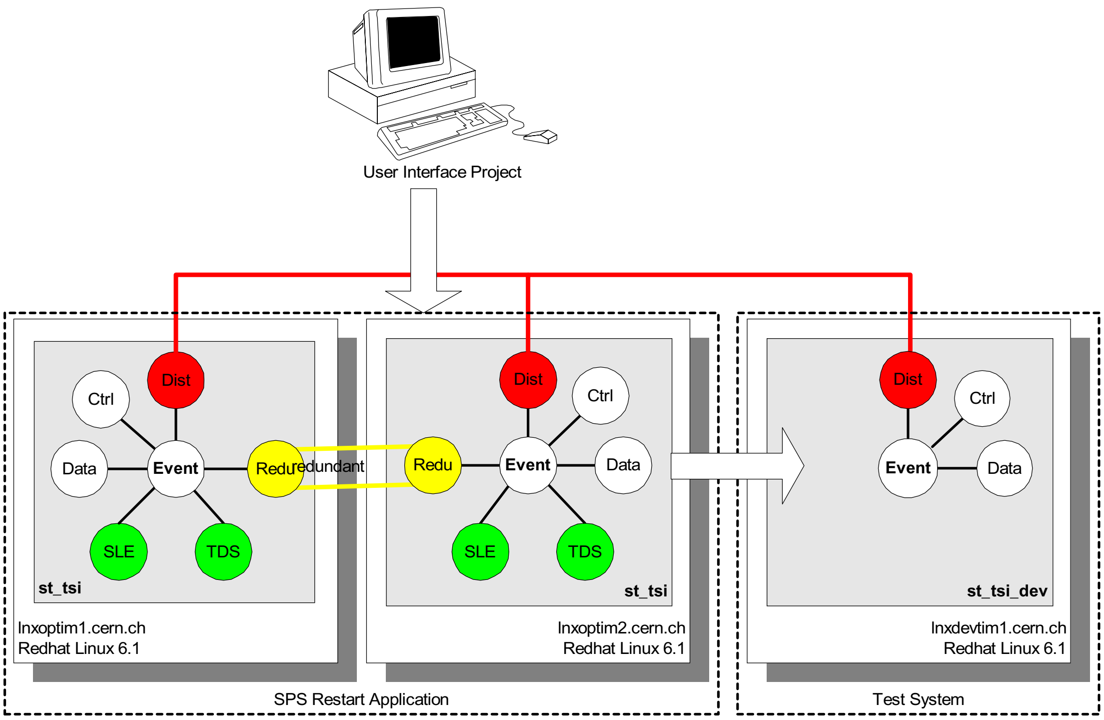


Figure 6-2 PVSS Set-up for distribution tests

6.1.2 SL-Equip Driver

The SL-Equip driver was thoroughly tested towards the end of the implementation phase. Its correct functioning is crucial for the entire SPS Restart Application. First of all, it had to be ensured that the driver conforms to its specification and provides all the required functionality (see 3.2.2 and 4.2), and then it had to be checked whether all data acquired and sent by the driver is correct.

It goes without saying that read and write actions could not immediately be tried out on operational equipment, for the risk of accidental damage would have been intolerable. For this reason, a piece of non-functional equipment supporting all SL-Equip modes without causing any hardware action was used for a first series of tests. Only when these tests had been completed successfully, the driver was tested on operational SPS equipment.

On the PVSS side, the tests were prepared by creating a new DPT with elements of all types supported by the SL-Equip driver (see Table 4-3). A DP of this type was instantiated and *_address* configs were attached to all the DPEs in order to connect them to the test equipment. Subsequently, read and write actions were performed in order to test data acquisition and sending commands for all supported data types. The following (non-exhaustive) list gives examples of test cases that were executed:

- New *_address* configs were attached to DPEs via the PVSS PARA module and and via the PVSS ASCII Manager. They were configured in a way that the DPEs were connected to the SL-Equip driver in order to verify whether new address information is (a) transmitted to the driver and (b) correctly processed.
- Different parameters of existing *_address* configs (e.g. SL-Equip address, polling interval etc.) were modified in order to check whether the driver is capable of reacting to these modifications.
- Existing *_address* configs were removed via the PVSS PARA module in order to check whether the address information is equally removed from the driver's internal lists. This was to ensure that the driver does not continue to acquire data that is not used/required by PVSS.
- Data was written to SL-Equip in order to check if the information is sent in the correct format.
- Data was read from SL-Equip in order to check if the information is read out and converted in the correct format.
- etc.

Some dysfunctional tests were also performed in order to check the driver's error handling (e.g. if invalid addresses are rejected). The debug mechanism described in the previous chapter proved to be very useful during testing, especially for checking whether the driver's internal lists of data points are managed correctly (adding/removing *_address* configs). Furthermore, several implementation mistakes in the transformation classes (see 5.2.2.6) could be detected, located and corrected in an efficient way.

As the SL-Equip driver has to run in a technical service context and must be available 24 hours per day, 365 days per year without interruption, the detection of memory leaks was a main concern during testing/debugging. For this reason, *ParaSoft's Insure++* suite, a comprehensive tool suite for error detection in C/C++ programs, was used to spot bugs and inefficiencies in memory handling.

Performance and load tests could not be performed due to a lack of development time.

6.1.3 Static Configuration Database and Data Loaders

This section covers the test procedure for the static configuration database described in 4.3, its data import scripts and procedures (4.3.2) and the SQL loader script for data extraction (4.3.3). Basically, the configuration database works "off-line" and has no run-time connection to the PVSS system. A connection to PVSS is only established when the text file produced by the export script is injected to PVSS by means of the ASCII Manager. The approach that was chosen for testing the off-line database was thus different from the test methods described in the previous sections. The whole functionality of the database system (import, storage and export of configuration data) was tested in one big test case, consisting of five steps presented in below. Before the test could be executed, however, a number of preconditions had to be established:

- The TDRefDB table structure described in 4.3.1.2 as well as the user views described in 4.3.1.3 have been created.

- The reference tables (PVSS_ADDRESS_TYPE, PVSS_ADDRESS_DATATYPE, PVSS_ADDRESS_MODE, PVSS_DISTRIB_TYPE, PVSS_DRIVER and PVSS_DPE_TYPE) have been filled with data correctly.
- The remaining tables (PVSS_DPT, PVSS_DPE, PVSS_DP, PVSS_DPE_TYPEREF, PVSS_ADDRESS and PVSS_DPE_COMMENT) contain no data.
- The VPTS_PVSS view exists and selects existing TDS configuration data from the TDRefDB (see 4.3.2.2).
- The data contained in the VPTS_PVSS view is consistent (no duplicate identifiers, no unexpected NULL values etc.).
- A set of correctly formatted SL-Equip configuration files (see 4.3.2.3.1) is available.
- The PVSS system for the SPS Restart Application is correctly set up and running (required for test step (5) only).

As soon as these preconditions had been established, the five test steps listed below were executed. Each test step is followed by a postcondition that represents the immediate result of the action performed:

(1) Execute the stored procedures for importing TDS configuration information. *Postcondition*: The PVSS_DPT, PVSS_DPE, PVSS_DP, PVSS_ADDRESS and PVSS_DPE_COMMENT tables have been filled with data from the VPTS_PVSS view.
(2) Execute the Perl script for validating and correcting the existing configuration files. *Postcondition*: A correctly formatted SL-Equip configuration file containing validated and corrected configuration data has been generated.
(3) Execute the Perl script for importing SL-Equip configuration information. *Postcondition*: The data contained in the corrected SL-Equip configuration file has been imported in the PVSS_DPT, PVSS_DPE, PVSS_DP and PVSS_ADDRESS tables.
(4) Execute the SQL script for extracting data from the TDRefDB.
Postcondition: An ASCII Manager-compatible text file containing all PVSS configuration information stored in the TDRefDB tables (see 4.3.1.2) has been generated.
(5) Import the generated text file into the PVSS system by means of the ASCII Manager. *Postcondition*: The DPTs, DPs, _address configs, _distrib configs and comments specified in the input file have been created in the PVSS system.

In order to verify whether the test was successful, the postconditions listed above had to be checked. Naturally, the correctness of the imported and exported data could not be verified for all data only but by means of some randomly chosen examples. As all the postconditions were met for the sample data, the test of the configuration database system was considered as successful.

6.1.4 User Interface Panels

The application's user interface described in chapters 4.4 and 5.4 could not be tested "stand-alone", for it requires at least a running PVSS system with TDS and SL-Equip data points defined. Ideally, the SL-Equip and TDS drivers should also be running in order to verify if the machine state displayed by the SPS Restart Application is identical with the machine state displayed by existing TCR applications used for comparison.

When the panel was tested on the PVSS system for the SPS Restart Application (see chapter 4.1), it displayed exactly the same machine states as the TCR applications (see Figure 5-4, for example). This proves that the whole data acquisition chain –from the driver up to the user interface panel – works. All the same, the panel's functionality also needed to be tested for other machine states (e.g. when one of the subsystem fails, when information about a certain subsystem is temporarily unavailable etc.). It goes without saying that it was out of question to cause a malfunction of the particle accelerator just for testing a new PVSS panel. For this reason, failures had to be simulated by changing values internally in PVSS. An example of such a simulation is given below.

Figure 6-3 shows a screenshot of the PVSS PARA module that is used to edit DPTs and DPs at run-time. The current values of read-only DPEs can be changed without affecting the "real value" in the connected hardware element. The value is only sent to the hardware if the DPE concerned is configured for sending commands (write direction). allows the configuration of all DPs of a system as well as changes of the current value. For instance, we could change the value of the DP representing the voltage on the 18kV bus bar (see chapter 4.4, Figure 4-13) to 100.000 Volt.

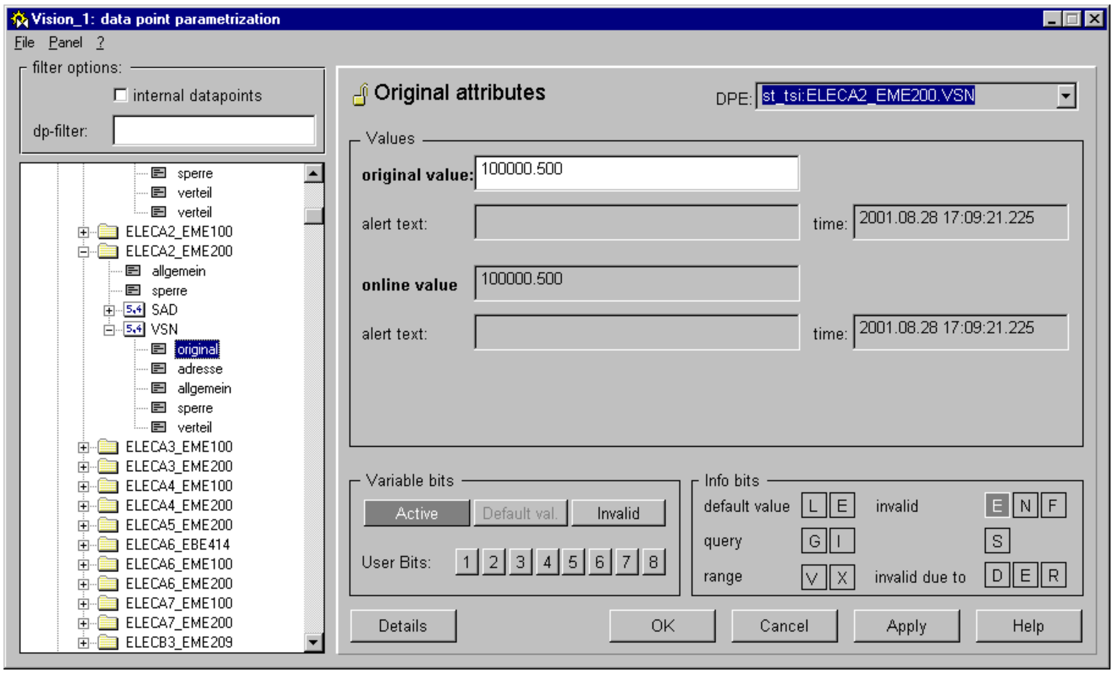


Figure 6-3 Screenshot of the PVSS PARA module during test execution

The application's user interface should react to this value change and change the colour of the box representing the *18 kV subsystem* of BA2 has changed to red (`ST_FAULT`). Figure 6-4 shows the result of the test.

Many other tests like the example above were tried out and all of them delivered the expected results.

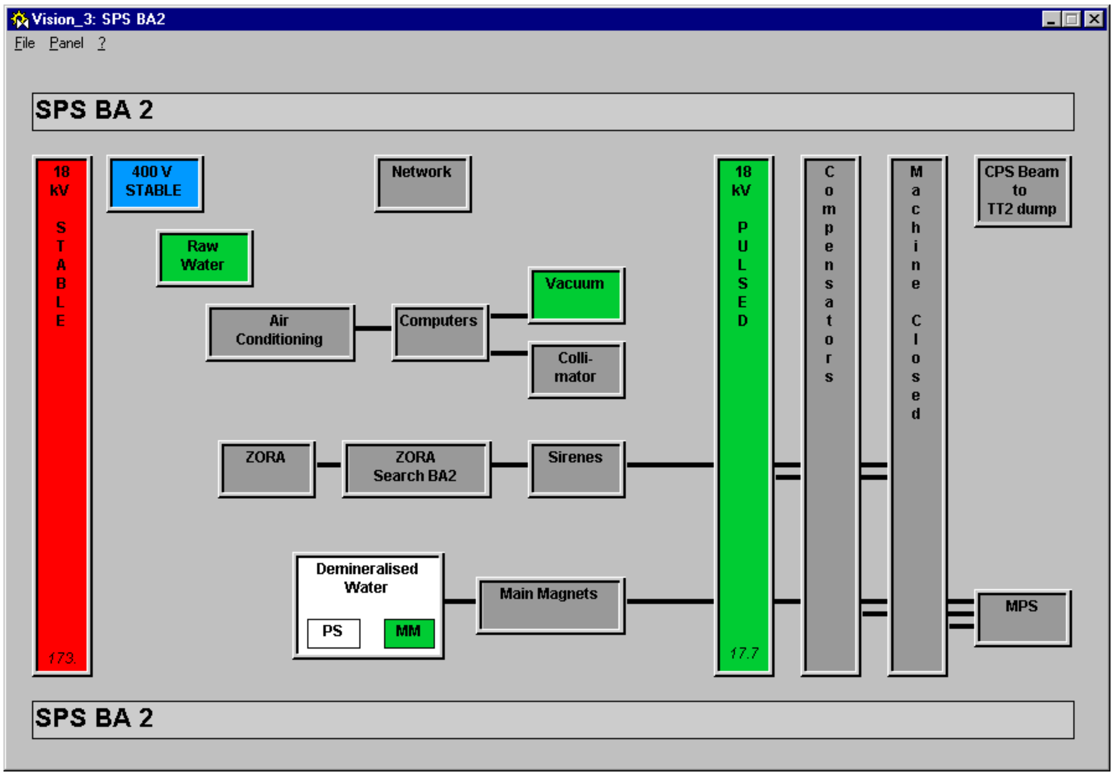


Figure 6-4 Screenshot of the BA2 mimic diagram during test execution

6.2 System Tests

As the tests of the user interface panel described in the previous section required a fully configured PVSS system including SL-Equip and TDS drivers, they can be regarded as a first series of system tests. A complete system test including functional tests, performance tests, stress tests and load tests will be performed as soon as the entire SPS Restart Application, including the panels to be implemented by TCR operators, is finished. A test plan document defining the test suite to be used for the acceptance tests is being prepared.

7. CONCLUSION

This last chapter summarises the main points of this thesis. The goal of the work is reiterated and a summary of the proposed solution is presented. Furthermore, some future extensions and potential improvements are suggested.

7.1 Goal and Solution

The aim of this thesis was the development of a SCADA application (see chapter 2.1) for monitoring the start-up of the Super Proton Synchrotron, CERN's second largest particle accelerator, after major breakdowns. The application had to be based on PVSS II, the CERN recommended SCADA product, developed by the Austrian company ETM (see chapter 2.2).

The problem posed in chapter 3 was broken down to four interdependent subtasks:

(1) A redundant and distributed PVSS II system had to be set up on two UNIX servers as a basis for the application.
(2) A PVSS Driver Manager for doing data exchange between PVSS and CERN's SL-Equip middleware (see chapter 2.3) had to be designed and implemented.
(3) An off-line database system for managing static PVSS configuration data and importing it to PVSS II had to be developed.
(4) Several mimic diagrams, so-called PVSS panels, for the application's user interface had to be created.

(1), (2) and (4) are closely related and correspond to the layers of the SCADA system's three-tier architecture (see Figure 2-2): the driver corresponds to the data layer, the PVSS II core system to the co-ordination and storage layer and the mimic diagrams to the user interface (presentation) layer.

The set-up and configuration of the PVSS II system was a challenge. For one thing, *high dependability* was a central design requirement, as the SPS Restart Application has to run in two of CERN's main control rooms and is therefore supposed to be available 24 hours a day, 365 days a year. The possibility of doing *data exchange with other PVSS systems* at CERN was also demanded. Furthermore, the system had to be installed on different operating systems: Redhat Linux 6.1 and Microsoft Windows NT 4.0/Windows 2000. These requirements and constraints have led to a redundant, distributed and scattered PVSS system that had to be well tested before it could become operational. The first series of system tests was successful, as described in chapter 6.

The *SL-Equip Driver Manager* has been developed following the Unified Modelling Language (UML) methodology. After a thorough analysis of the problem, object-oriented class and object designs have been established. The driver has been implemented in C++ on a Redhat Linux 6.1 platform, using the PVSS and SL-Equip APIs. Contrary to other PVSS drivers, the SL-Equip driver is only available for Linux platforms, for the SL-Equip API has not been ported to Microsoft Windows platforms yet. The driver has been debugged and tested intensively in order to guarantee high stability and availability.

The design for the *static configuration database* described in chapter 4.3 has been established in accordance with the ST/MO group's database design rules. A server model for the database has been designed using the Oracle Designer 6 tool suite and then automatically exported to an Oracle 8 database. In addition to the database structure for storing PVSS data point types, data points and configs (see 2.2.2), a set of PL/SQL procedures and Perl scripts for importing existing configuration data from various sources has been designed and implemented. Furthermore, an SQL script for extracting configuration data from the database and exporting it to ASCII text files that can be injected to PVSS by means of the PVSS ASCII Manager has been developed.

A prototype for the SPS Restart Application's *user interface* has been implemented as a series of PVSS panels. The panel layout is based on functional diagrams of the Super Proton Synchrotron, developed in the course of the Gestion Technique de Pannes Majeures project (see 1.2). The panel has been animated with live data acquired by the SL-Equip and TDS Driver Managers and reflects the current state of one of the SPS sextants (BA2).

7.2 Unsolved Problems

This section covers open issues – parts of the problem that have not been solved in the course of this thesis work.

Although the implementation of the *full series of user interface panels* was not included in the scope of this thesis, it has to be mentioned that the user interface still needs to be completed before the SPS Restart Application can become operational. At least 8-10 further panels similar to the one described in chapter 5.4 need to be created in co-operation with TCR operators. Of course, the panel developed in the course of this thesis work will serve as an example for future developments.

7.3 Possible Extensions

This section deals with possible extensions to the components of the SPS Restart Application. In my opinion, the SL-Equip driver and the PVSS configuration database could both be improved.

Regarding the *SL-Equip Driver Manager*, it is thinkable to extend its functionality to all *data types* (modes) *supported by SL-Equip*. Currently, only the data types listed in Table 4-3 are supported. Such an extension is not at all necessary for the SPS Restart Application. However, it would increase the usability of the driver for other projects.

Regarding the static *PVSS configuration database*, the current data loading strategy is a very rudimentary solution. First of all, there is no way to edit the configuration information contained in the TDRefDB in a reasonable way. As a consequence, a tool for modifying PVSS configuration data directly in the database, e. g. via a Web interface or an Oracle Forms application, would be very useful. Second, the data loading procedure is not very efficient, for all information contained in the configuration database is first exported to an ASCII file that is then injected to PVSS via the ASCII Manager. Even if only one database record (e.g. one DP) changes, the whole file has to be reloaded – a procedure that took more than one hour during tests. For this reason, it would be very useful to have a more flexible database loading tool, e. g. an additional PVSS API Manager that connects to PVSS and the TDRefDB respectively and synchronises the two databases. Naturally, the development of such an API Manager requires a lot of development effort and has to be done in a separate project.

7.4 Concluding Remarks

Summing up, we can say that the project was very interesting and highly challenging from an organizational as well as from a technical point of view. Co-operation of several organic units at CERN, notably the Technical Control Room, the SL/CO group and the ST/MO/IN section was crucial for the project's success, for expert knowledge in many different domains was required (e.g. knowledge about the systems involved in the SPS restart, knowledge about the SL-Equip architecture etc.). A lot of different technologies, e.g. SCADA systems, object-oriented design and implementation, UNIX and Microsoft Windows operating systems, database management systems etc., had to be mastered to successfully develop all the system's components. However, a global vision of the system was equally important, to integrate the application's components in a way that a highly dependable and reliable PVSS application, ready to be deployed to the CERN control rooms, was reached.

8. TABLE OF FIGURES

9. TABLE OF LISTINGS

10. LIST OF TABLES

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APPENDIX A. PVSS SERVER CONFIGURATION

A.1 “SET_REDU” File on the Redundant PVSS Servers

The `SET_REDU` file of a PVSS project is checked by the PVSS start-up script in order to determine whether the PVSS project shall be started in redundant or stand-alone mode. The redundant hosts, all view hosts and the mount point for the redundancy partner’s project directory must be specified.

```
REDUHOST_1=lnxoptim1
REDUHOST_2=lnxoptim2
VIEWHOST_1=pcst291
MOUNTPOINT=/nfs
```

A.2 “config” File on the Redundant PVSS Servers

The `config` file is the central PVSS configuration file and read by all managers’ Resource classes. The Managers first read the general section ([general]) and then jump to their own specific section (e.g. [redu] for the Redundancy Manager, [dist] for the Distribution Manager etc.). The listing below only contains entries that are non-standard. All lines that have been copied from the sample configuration file for redundant systems have been removed.

```
[general]
# These two paths must be identical on both machines.
pvss_path = "/opt/pvss/pvss2_v2.11.1"
proj_version = "2.11.1"
proj_path = "/home/PVSS/ST_TSI"

# The names of the redundant hosts are defined as “host1$host2”.
dataHost  = "lnxoptim1$lnxoptim2"
eventHost = "lnxoptim1$lnxoptim2"

# Language settings (US English)
langs = "en_US.iso88591"

distributed = 1

[dist]

# Configure connections to distributed systems
# ---------------------------------------------------------------------
#            Man  Hostname                             # System name
# ---------------------------------------------------------------------
  distPeer = 1   "lnxoptim1$lnxoptim   0    0    360   # "st_tsi"
  distPeer = 2   "pcst100"             0    0    360   # "st_tsi_tst"
# ---------------------------------------------------------------------

[redu]

# Determine which redundancy manager shall try to establish a
# connection to the other. The client (1) is active by default.

(lnxoptim1) client = 1
(lnxoptim2) client = 0

# server port for the redundancy manager (identical on both machines)
portNr = 8989
```

```
# primary connection to the redundancy partner
(lnxoptim1) ipPeer = "lnxoptim2"
(lnxoptim2) ipPeer = "lnxoptim1"

# (optional) secondary connection to the redundancy partner
(lnxoptim1) ipPeer = "lnxoptim2_pvss"
(lnxoptim2) ipPeer = "lnxoptim1_pvss"
```

A.3 "progs" File on the Redundant PVSS Servers

The `progs` file is read by the PVSS start-up script in order to determine the managers to be started as well as their command-line parameters. The `progs` file listed below will cause the PVSS start-up script to attempt a recovery with the redundancy partner and to launch the following managers:

- Database Manager (PVSS00data)
- Event Manager (PVSS00event)
- Control Manager with number 1 (PVSS00ctrl) for running PVSS standard scripts
- Control Manager with number 2 (PVSS01ctrl) for running the PVSS redundancy script
- Redundancy Manager (PVSS00redu)
- Distribution Manager (PVSS00dist) with manager number 1
- TDS Driver Manager (PVSS00tds) with driver number 1
- SL-Equip Driver Manager (PVSS00sle) with driver number 2

```
START_RECOVERY
#clr_ip -a lockmgr &
#lm_ip -f 600&
PVSS00data DUMMY RECOVER -log +stderr&
PVSS00event DUMMY RECOVER -log +stderr&
PVSS00ctrl DUMMY -log +stderr -f pvss_scripts.lst&
PVSS01ctrl DUMMY -num 2 redu_ctrl -log +stderr&
PVSS00redu DUMMY -log +stderr&
PVSS00dist DUMMY -num 1 -log +stderr&
PVSS00tds DUMMY -log +stderr&
PVSS00sle DUMMY -num 2 -log +stderr&
```

APPENDIX B. SL-EQUIP DRIVER (SLESRVHDL)

The listing below contains the code of the `singleQuery` and `writeData` methods of the *SleSrvHdl* (SL-Equip Server Handler) class. The design description of the methods is presented in chapter 4.2.3.1.2, the implementation is explained in 5.2.2.5. The code of the `singleQuery` method has been abridged in such a way that the listing only contains the acquisition of floating-point values although the SL-Equip driver also supports the acquisition of integer and string values.

```
/*
 * Convert an integer number to a binary value represented by
 * an array of bools.
 */
void intToBinary(int x, bool bin[8]) {

  int i;
  for (i=7; i >= 0; i--) {
    bin[i]= (x%2 == 1);
    x=x/2;
  }
} // intToBinary;

/*
 * Retrieve a value from SL-Equip and communicated it to PVSS.
 */
void SleSrvHdl::singleQuery(HWObject *objPtr)
{
  struct INFOREC info;          // SL-Equip address structure
  unsigned short asynch;
  unsigned long cycle;
  unsigned short bytecount;     // length of data returned by SL-Equip
  short cnt;
  char errmsg[80];              // potential SL-Equip error message.

  // Find the SleMapObj corresponding to the HWObject parameter
  SleMapObj* existingObjPtr =
   (SleMapObj*)DrvManager::getHWMapperPtr()->findHWObject(objPtr);

  // Initialize all variables for the EQUIP() call
  info = existingObjPtr->getInfoRec();
  errmsg[0]='\0';
  bytecount = existingObjPtr->getDlen();
  asynch = 0;
  cycle = 0;

  // Copy the name of the equipment host to global SL-Equip variable,
  // as required by the SL-Equip library
  strcpy(EqpHostname, existingObjPtr->getHost());

  // Retrieve the data and convert it to the correct format,
  // according to the data type
  switch(existingObjPtr->getType()) {
    case SleTransFloatType: {
      double data = 0.0;
      cnt = EQUIP(&info, &asynch, &cycle, &bytecount,
                  errmsg, (char*) &data);
      // 1.) Convert data to PVSSchar
      PVSSchar *pBuf = new PVSSchar[existingObjPtr->getDlen()];
      *(double*) pBuf = (double) data;
```

```
      // 2.) Fill SleMapObj
      objPtr->setType(existingObjPtr->getType());
      TimeVar time;
      objPtr->setOrgTime(time);
      objPtr->setDlen(existingObjPtr->getDlen());
      objPtr->setObjSrcType(srcSingleQ);
      objPtr->setData(pBuf);
      // 3.) Set user and invalid bits (if necessary)
      if ( cnt != 0) {
        // set status bits to VALID and clear user bits
        objPtr->clearSbit(DRV_INVALID);
        for (int i= 0;i < 8; i++)
          objPtr->clearSbit(DRV_USERBIT1 + i);
      }
      else {
        char errStr[3];
        strncpy(errStr, errmsg, 2);
        errStr[2]='\0';
        // set DRV_INVALID bit and print an error message to the log
        objPtr->setSbit(DRV_INVALID);
        cerr << "ERROR on " << objPtr->getAddress()
          << " [SleSrvHdl][singleQuery]: (" << EqpErrno << ") err="
          << errmsg << endl;
        // convert the EqpErrNo supplied by SL-Equip to binary format
        bool binErrNo[8];
        intToBinary(atoi(errStr), binErrNo);
        // set the user bits accordingly
        for (int i= 0; i < 8; i++)
          if (binErrNo[i])
            objPtr->setSbit(DRV_USERBIT1 + i);
          else
            objPtr->clearSbit(DRV_USERBIT1 + i);
      }
      // 5.) Call toDP function
      DrvManager::getSelfPtr()->toDp(objPtr, existingObjPtr);
      delete pBuf;
      break;
    }
    case SleTransStringType: {
      ...
      break;
    case SleTransIntType: {
      ...
      break;
    default:
      cerr << "ERROR on " << objPtr->getAddress() <<
        " [SrvHdl][singleQuery] Unexpected Transformation type: " <<
        (unsigned long) existingObjPtr->getType() << endl;
  } // switch
} // singleQuery

PVSSboolean SleSrvHdl::writeData(HWObject *objPtr){
  struct INFOREC info;          // SL-Equip address structure
  unsigned short asynch;
  unsigned long cycle;
  unsigned short bytecount;     // number of bytes to be written
  char errmsg[80];              // potential SL-Equip error msg.

  // Find SleMapObj corresponding to the HWObject parameter
  SleMapObj* sleObjPtr =
```

```
    (SleMapObj*)DrvManager::getHWMapperPtr()->findHWObject(objPtr);

  // Initialize data and bytecount according to parameter information
  PVSSchar* data = objPtr->getData();
  if (objPtr->getType() == SleTransStringType )
    bytecount = strlen((char*)(objPtr->getData()));
  else
    bytecount = objPtr->getDlen();

  // Initialize all additional variables for the EQUIP call
  info = sleObjPtr->getInfoRec();
  errmsg[0]='\0';
  asynch = 0;
  cycle = 0;

  // Send information to SL-Equip
  if (EQUIP(&info, &asynch, &cycle, &bytecount, errmsg,(char*) data))
    // Everything OK → return PVSS_TRUE
    return PVSS_TRUE;
  else {
    // Error → print SL-Equip error message and return PVSS_FALSE
    ErrHdl::error(
      ErrClass(
        ErrClass::PRIO_WARNING,
        ErrClass::ERR_PARAM,
        ErrClass::UNEXPECTEDSTATE,
        "SleSrvHdl", "writeData", EqpErrMessage
      )
    );
    return PVSS_FALSE;
  } // else
} // writeData
```

APPENDIX C. SL-EQUIP DATA IMPORT SCRIPTS

This appendix lists the code of the two Perl scripts described in section 5.3.2.2 of the Implementation chapter. The first script listed below merges the contents of a given set of SL-Equip configuration files, tests all actions associated with the equipment and produces a single corrected configuration file.

```
#!/usr/bin/perl

# Check if the user has entered thee command line arguments.
# If not, print an error message and abort execution.
if ($#ARGV ne 2) {
  print "The following $#ARGV parameters will be used:\n";
  print "  input dir:     $ARGV[0]\n";
  print "  input pattern: $ARGV[1]\n";
  print "  output file:   $ARGV[2]\n";
  exit;
}

# Specify a directory for the data files
my ($filedir) = $ARGV[0];

# Read the file filter (e.g. "*.dat") from the command line and
# bring it in regular expression format (e.g. ".*\.dat")
my($filefilter) = $ARGV[1];
$filefilter =~ s/\./\\\./g;
$filefilter =~ s/\*/\.\*/g;

# Read the name of the output file from the command line.
my ($outfile) = $ARGV[2];

# Declare global variables
my (@filenames);              # list of all files to be processed
my (@all_equipments);         # list of all equipments
my (%equipment_map) = ();     # associative list of eqpts. and actions
my (@all_actions);            # list of all actions
my ($action_list);            # string representation of the action list
my ($filenames);

# Get a list of all files from the specified directory whose name matches
# the specified pattern.
opendir (DIR, $filedir);
  my (@filenames) = grep { /$filefilter/ } readdir DIR;
closedir DIR;

print "Importing Sl-Equip equipment definitions ...\n";
print "---------------------------------------------\n";

# Process the files one by one
foreach $file (@filenames)  {
  print "  importing " . $file . "...\n" ;

  # Read all lines in the file
  my (@lines);
  open (FILE, $filedir . "/". $file);
    @lines = <FILE>;
  close (FILE);

  # Process each of the lines
  foreach $line (@lines) {
```

```
    # Split the line into the equipment name and a list of
    # accepted actions
    ($trash, $equipment, $actions) = split (/\s+/, $line, 3);

    # Add the equipment name to the equipment list.
    push (@all_equipments, $trash . " " . $equipment);

    # Add all actions contained in the line to the action list
    @actions = split (' ', $actions);
    push (@all_actions, @actions);
  }
}

# Remove duplicate equipment names and duplicate actions
# and sort the lists.
undef %saw;
@all_equipments = grep (!$saw{$_}++, @all_equipments);
@all_equipments = sort {$a cmp $b} @all_equipments;

undef %saw;
@all_actions = grep (!$saw{$_}++, @all_actions);
@all_actions = sort {$a cmp $b} @all_actions;

# Convert the action list to a string and remove the dummy action "---"
$action_list = join (' ', @all_actions);
$action_list =~ s/^--- //;

# For each equipment, test all actions contained in @all_actions using
# a simple SL-Equip client. Eliminate actions for which a value other
# than 0 is returnd and build up a map of all equipments with their
# supported actions.
foreach $equipment (@all_equipments) {
  local($actions);

  ($trash, $name) = split (' ', $equipment, 2);
  ($family, $member) = split ('_', $name, 2);

  # Test each action for the equipment currently processed.
  foreach $action (@all_actions) {
    $return=  system("./chk_equip $family $member $action RAR");
    if ( $return eq  0 ) {
      $actions = $actions . " " . $action;
    }
  }

  # Add the equipment with its supported actions to the map.
  $equipment_map{$trash . " " . $name} = $actions;
}

# Print the results to the output file
open (FILE, ">$outfile");
  while (( $equipment, $actions ) = each %equipment_map) {
    print FILE $equipment . "$actions\n";
  } #while
close (FILE);

exit;
```

The following scripts reads a corrected SL-Equip configuration file and enters its contents in the TDRefDB, using the Perl Database Interface (DBI) module.

```
#!/usr/bin/perl

# Import the DB Interface (DBI) module
use DBI;

# Create a DB connection to ORACTCR and check for errors.
my $dsn = 'dbi:Oracle:host=oradev;sid=D';
my $user = 'control_st';
my $pass = 'tcr';

my $dbh = DBI->connect($dsn, $user, $pass);
unless (defined $dbh) {
  die $DBI::errstr;
}

# Determine the name of the input file (either use the file name
# specified on the command line or "./in.t" by default).
my ($infile) = "./in.t";
if (($#ARGV + 1) == 1) {
  $infile = $ARGV[0];
}

# Read the given input file
my @all_lines;
open (FILE, $infile);
  @all_lines = <FILE>;
close (FILE);

# Duplicated the array of input lines (needed later)
my @lines = @all_lines;

# Remove element names and only keep a list of distinct actions
foreach $line (@all_lines) {
  #remove empty members
  $line =~ s/ ---//g;
  $line =~ s/\n//g;

  # remove family and member from the line
  $line =~ s/^\w*\/\w*\s*\w*_\w*\s*//;

  #sort all actions in the line
  $line = join (' ', sort {$a cmp $b} split(/ /, $line));
}

# Sort the equipment names
@all_lines = sort {$a cmp $b} @all_lines;

# Remove duplicate equipment names
undef %saw;
@all_lines= grep (!$saw{$_}++, @all_lines);

my ($cnt) = 1;
my (%types) = ();
foreach $line (@all_lines) {
  $types {$line} = "ELEC_" . $cnt;
  print $types{$line} . "*\t: *" . $line . "*\n";
  $cnt++;
```

```
}

undef $actions;
undef $type;
my $DPTYPE_COMPLEX = 1;
my $DPTYPE_FLOAT = 22;
my $type;
my ($actions)= ();
my(%elements) = ();
my $trash;
my $name;
my $actions;
my $reference;
my @dpt_id;
my @dpe_id;
my @dp_id;
my @addr_id;

# Prepare SQL statement for creating PVSS_DPT record
my $sth_dpt = $dbh->prepare(
    "INSERT INTO PVSS_DPT VALUES " .
    "(?, ?, ?, 'SL-Equip Electrical Equipment')"
);
# Prepare SQL statement for creating PVSS_DPE record
my $sth_dpe = $dbh->prepare(
    "INSERT INTO PVSS_DPE VALUES (?, ?, ?, ?, NULL)"
);
# Prepare SQL statement for creating PVSS_DP record
my $sth_dp = $dbh->prepare(
  "INSERT INTO PVSS_DP VALUES (?, ?, ?, 'SL-Equip')"
);
# Prepare SQL statement for creating PVSS_ADDRESS record
my $sth_addr = $dbh->prepare(
  "INSERT INTO PVSS_ADDRESS VALUES (" .
  "?, ?, ?, 16, ?, 0, 4, 0,  to_date('01.01.1970 00:00:00', " .
  "'DD.MM.YYYY HH24:MI:SS'), to_date('01.01.1970 00:02:00', " .
  "'DD.MM.YYYY HH24:MI:SS'), to_date('01.01.1970 00:00:10', " .
  " 'DD.MM.YYYY HH24:MI:SS'), 8, 'SL-Equip', 56, 2)"
);
# Prepare SQL statement for selecting next DPT_ID from database
my $sth_dpt_id_nextval = $dbh->prepare(
  "SELECT dpt_id.nextval FROM dual"
);
# Prepare SQL statement for selecting next DPE_ID from database
my $sth_dpe_id_nextval = $dbh->prepare(
  "SELECT dpe_id.nextval FROM dual"
);
# Prepare SQL statement for selecting next DP_ID from database
my $sth_dp_id_nextval = $dbh->prepare(
  "SELECT dp_id.nextval FROM dual"
);
# Prepare SQL statement for selecting next ADDR_ID from database
my $sth_addr_id_nextval = $dbh->prepare(
  "SELECT addr_id.nextval FROM dual"
);
# Prepare SQL statement for finding DPT_ID by DPT_NAME
my $sth_dpt_id = $dbh->prepare(
  "SELECT dpt_id FROM pvss_dpt WHERE dpt_name = ?"
);

# Prepare SQL statement for finding DP_ID by DP_NAME
```

```
my $sth_dp_id = $dbh->prepare(
  "SELECT dp_id FROM pvss_dp WHERE dp_name = ?"
);
# Prepare SQL statement for finding DPE_ID by DPT_ID and DPE_NAME
my $sth_dpe_id = $dbh->prepare(
  "SELECT dpe_id FROM pvss_dpe " .
  "WHERE dpe_dpt_id = ? AND dpe_name = ?");

while ( ($action_str, $type) = each %types ) {
  local (@actions) = split(/\s+/, $action_str);

  $sth_dpt_id_nextval->execute();
  @dpt_id = $sth_dpt_id_nextval->fetchrow_array;

  $sth_dpt->execute($dpt_id[0], $type, $DPTYPE_COMPLEX)
    or die $DBI::errstr;
  foreach $action (@actions) {
    $sth_dpe_id_nextval->execute();
    @dpe_id = $sth_dpe_id_nextval->fetchrow_array;

    $sth_dpe->execute ($dpe_id[0], $dpt_id[0], $action, $DPTYPE_FLOAT)
      or die $DBI::errstr;
    $sth_dpe_id_nextval->finish();
  }
  $sth_dpt_id_nextval->finish();
}

foreach $line (@lines) {
  $_ = $line;
  ($trash, $name, $actions) = split (' ', $line, 3);
  $actions =~ s/\s?---//g;
  $actions =~ s/\n//g;
  $actions = join (' ', sort {$a cmp $b} split (/ /, $actions));
  $actions =~ s/^\s//g;
  $elements{$name} = $types{$actions};
}

while ( ($name, $type) = each %elements ) {
  $sth_dpt_id->execute($type);
  @dpt_id = $sth_dpt_id->fetchrow_array;
  $sth_dp_id_nextval->execute();
  @dp_id = $sth_dp_id_nextval->fetchrow_array;

  $sth_dp->execute($dp_id[0], $name, $dpt_id[0]);
  $sth_dpt_id->finish();
  $sth_dp_id_nextval->finish();
}

my (%actions_by_type) = reverse %types;
while ( ($name, $type) = each %elements ) {
  @actions = split(' ', $actions_by_type{$type});
  foreach $action (@actions) {
    $sth_addr_id_nextval->execute();
    @addr_id = $sth_addr_id_nextval->fetchrow_array;
    $sth_dp_id->execute($name);
    @dp_id = $sth_dp_id->fetchrow_array;
    $sth_dpe_id->execute($dpt_id[0], $action);
    @dpe_id = $sth_dpe_id->fetchrow_array;

    $reference = $name . "_" . $action . "_RAR";
    $sth_addr->execute(
```

```
      $addr_id[0], $dp_id[0], $dpe_id[0], $reference
    );
    $sth_addr_id_nextval->finish();
    $sth_dp_id->finish();
    $sth_dpe_id->finish();
  }
}
```

APPENDIX D. DATA EXPORT: DATA LOADER SCRIPT

This appendix lists the data loader script used for extracting data from the TDRefDB, generating a file that can be injected to PVSS via the ASCII Manager. The design of the data loader is presented in chapter 4.3.3, the implementation is described in section 5.3.3. The script can be launched from an SQL*PLUS prompt using the `START` command.

```
/*********************************************************/
/*  PVSS database loading from TDRefDB (ASCII file)      */
/*                                                       */
/*  Author: J. Stowisek, ST/MO                           */
/*  Created on 06/08/2001                                */
/*  Last modified on 11/08/2001                          */
/*                                                       */
/*  Generates an ASCII Manager-compatible text file from */
/*  the configuration information stored in TDRefDB tables */
/*                                                       */
/*  Uses: VPVSS_DPT, VPVSS_DP, VPVSS_DPE, VPVSS_ADDRESS, */
/*        VPVSS_DISTRIB, VPVSS_DPE_COMMENT.              */
/*                                                       */
/*  Usage: Run from SQL*PLUS prompt using the START command */
/*********************************************************/

/* O U T P U T   F O R M A T   S E T T I N G S */
set echo off
set termout off
set underline off
set heading off
set timing off
set feedback off
set flush off
set showmode off
set verify off
set headsep !
set embedded on
set document off
set linesize 240
set recsep off
set tab on
set trimout on
set trimspool on      /* remove blanks at the end of the line */
set warp on
set colsep '  '       /* column separator: a tab */
set pagesize 2000     /* we don't want page breaks */

/* R E D I R E C T   O U T P U T   T O   A   T E X T   F I L E */
spool c:\pvssconf

/* D A T A   P O I N T   T Y P E S   D E S C R I P T I O N   */

rem repheader '#DpType'

SELECT '#DPtype'      /* Comment */
FROM dual;
SELECT 'TypeName'     /* DPT section header */
FROM dual;

column A noprint
column B noprint
```

```
SELECT '1' A, dpt_name B, dpt_name || '.' ||
       dpt_name || '     ' || dpt_type
FROM vpvss_dpt WHERE dpt_name LIKE 'ELEC%'
UNION
SELECT '2' A, dpt_name B, LPAD('      ', DPE_LEVEL) ||
       DPE_NAME || '     ' || DPE_TYPE
FROM vpvss_dpe WHERE dpt_name LIKE 'ELEC%'
ORDER BY 2,1;

/* D A T A  P O I N T  I D E N T I F I C A T I O N  S E C T I O N */

SELECT '#Datapoint/DpId'   /* Comment */
FROM dual;
SELECT 'DpName     TypeName'  /* DP section header */
FROM dual;

SELECT dp_name || '      ' || dpt_name
FROM vpvss_dp
WHERE dpt_name LIKE 'ELEC%'
ORDER BY dp_name;

/* D I S T R I B U T I O N  S E C T I O N */

SELECT '#DistributionInfo' FROM dual;     /* Comment */
SELECT 'ElementName      TypeName    _distrib.._type    `
      _distrib.._driver' FROM dual;  /* Distribution section header */

SELECT dp_name || '.' || dpe_full_name || ' ' || dpt_name || ' ' ||
dist_type || '     \' || dist_drv_num
FROM vpvss_distrib;

/* P E R I P H E R A L  A D D R E S S  S E C T I O N */

SELECT '#PeriphAddrMain'  /* Comment */
FROM dual;

SELECT 'ElementName      TypeName    _address.._type
      _address.._reference     _address.._offset  _address.._subindex
      _address.._mode    _address.._start   _address.._interval
      _address.._reply   _address.._datatype      _address.._drv_ident'
/* Address section header */
FROM dual;

SELECT
  dp_name || '.' || dpe_full_name || '      ' || dpt_name || ' ' ||
  addr_type || '   "' || addr_reference || '"      ' ||
  addr_offset || ' ' || addr_subindex || '  \' || addr_mode || '      ' ||
  TO_CHAR(addr_interval, 'DD.MM.YYYY HH24:MI:SS') || '.000    ' ||
  TO_CHAR(addr_interval, 'DD.MM.YYYY HH24:MI:SS') || '.000    ' ||
  TO_CHAR(addr_interval, 'DD.MM.YYYY HH24:MI:SS') || '.000    ' ||
  addr_datatype || '     "' || addr_drv_name || '"'
FROM vpvss_address
ORDER BY dpt_name, dp_name, dpe_full_name;

/* C L O S E  T H E  O U T P U T  F I L E */
spool off
```