

# Integration of Industrial Equipment and Distributed Control Systems into the Control Infrastructure at CERN

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## Abstract

CERN Accelerators and Services have an existing large investment in control networks, fieldbuses, front-end process computers, workstations, system software and application programs. Increasingly, industrial equipment and complete Distributed Control Systems (DCS) are being installed to rejuvenate old and obsolete systems and new projects for LHC are taking shape.

The object of this paper is to report experience of CERN's control engineers on integration of industrial equipment and systems. Several projects are described covering a vast area of applications.

The paper presents several interfacing issues such as network connection of industrial equipment, software integration, homogeneous equipment access and alarm retrieval compatible with the existing Accelerators and Services Control System.

## 1 Introduction

For CERN's Accelerators and Technical Services an increasing number of industrial systems is being installed to rejuvenate old and obsolescent systems. Several projects concern the SPS accelerator which will be the injector for the future Large Hadron Collider which will start operating in 2005.

In addition, many new systems for the LHC are entirely specified from the beginning of the project to use industrial equipment. The control equipment concerned ranges from individual Programmable Logical Controllers (PLCs), through clusters of PLCs interconnected by a fieldbus, up to complete DCSs delivered to CERN as turnkey systems with their dedicated supervisor included.

These new industrial control components may or may not, need to use part of CERN's existing communication infrastructure. The technical requirements of these industrial systems upon CERN's control networks, and vice-versa, must be identified in terms of Response-Time, Bandwidth, Protocols, Availability and Reliability.

Integration of industrial software is another important issue. Depending on the level of the controls architecture at which industrial equipment is connected, the communication with pre-existing equipment poses different problems and challenges. CERN's control engineers have to provide the operators of the accelerators and technical services with a homogeneous man-machine interface and a coherent treatment of alarms generated by the various industrial systems and the existing control system.

To buy and to contract for industrial control equipment, it is essential to know beforehand what products manufacturers are offering and what level of expertise is required from the supplier. The technical specifications related to

the project must be written following standards and methodologies commonly in practice in industry.

Finally, to follow-up, to supervise the execution and to complete successfully industrial contracts requires the adhesion of both parties, CERN and the contractor, to a rigorous project management plan.

## 2 Typical applications of industrial systems

To illustrate the diversity of industrial systems installed at CERN, operational today or under development, we present some recent and significant projects. We describe the SPS Machine Access System, the CERN Site Access System, the SPS Smoke Detection and Tunnel Ventilation, the Interlock System of the SPS Main Magnet Power Converters and the Modernisation of the Beam Target Electronics.

### 2.1 SPS machine access system

The SPS machine access system covers both the access to the accelerator tunnel and to the North and West physics experimental areas. The access to the SPS tunnel is controlled by the machine operator while the experimental areas accesses are prepared and terminated by the physicists themselves by running programs from beam control terminals in their experimental barracks. These programs monitor the required critical elements to satisfy the conditions for access and then send the necessary commands to the door to allow entry. It is therefore important that the machine access system for the experimental zones is able to communicate with the machine operator and also with the tunnel access system directly. The SPS machine access system uses the multi-protocol communication capability of the controls network.

Three industrial PLCs and a HP-UX workstation are directly connected to the network; the PLCs control the access hardware, keys, film badges, grids, displays while the workstation runs the Factory-Link Supervisor and communicates via the Sinec H1 Protocol with the PLCs. The HP-UX acts as a gateway between the operator's X Terminal server and the PLCs [1].

### 2.2 CERN site access system

A CERN-wide site access system is being installed in three phases, first at 12 sites around the SPS Accelerator, then at 10 sites on the Swiss Meyrin area and the next phase will be at 17 sites around the LEP Collider.

Each remote site communicates by TCP/IP over the controls network via a local HP-UX computer that runs a proprietary supervisor and acts as a gateway between the local cluster of PLCs and the central access control room.

At a site, the local PLC cluster interfaces to gates, doors, badge-readers, lights, etc..

Each site is controlled remotely, but is also capable of operating autonomously in stand-alone mode, should a network problem occur. To allow local operation each site holds a subset of the central database of persons authorised to access a particular site.

At the central control room one finds HP-UX workstations, X-terminals and a global access server. The site access system consults a central CERN personnel database, to obtain individual access authorisation. Alarms, generated at the local sites, are sent for analysis to the central alarm server and for presentation to the site access operator.

### *2.3 SPS smoke detection and tunnel ventilation*

A global smoke detection and ventilation system is being installed in the SPS tunnel in order to detect fire and to activate the tunnel ventilation system according to a predefined strategic plan.

Each of the SPS tunnel arcs contains a number of smoke and fire detectors linked to a local PLC; on top of the tunnel pits are ventilators, motors and fans controlled by a second PLC. The tunnel PLCs are connected via a Profibus fieldbus to a master PLC located in each of the SPS surface buildings. Seven master PLCs will be directly connected to the controls network and the communication, between these master PLCs and the HP computer running a supervisory system under HP-UX, is done by a TCP protocol (Send/Receive interface, Transport Layer 4, RFC 1006).

In each SPS building and on top of the local tunnel pit there is a local synoptic display for the firemen depicting the status of the fire detection and ventilation systems. This local display is connected directly to the master PLC and consists of an industrial PLC from which full local operation of the ventilation system is possible. Remote operation and visualisation of the status of adjacent sites is also feasible when the network is operational and not affected by the fire. The global supervision is done from the firemen's central operation control room.

### *2.4 SPS main magnet power converters*

The control and interlock system of the main magnet power converters is obsolete and its replacement by a new one is necessary. The new interlock system is based on a technical infrastructure implemented with PLCs connected to a Profibus fieldbus.

The SPS main rectifiers stations (14 dipoles and 3 quadrupoles) are fed from an 18 kV substation located in the central electrical building. Cables bring the power and the remote control to the individual rectifiers. The distributed power converters around the SPS accelerator could imply considerable risks for the personnel and material. The control and interlock system detects all faults and may stop all the main power converters or, if it is necessary, switch off all 18 kV circuit breakers. Faults are displayed on the front panels of the individual converter and the information is transmitted to the beam

control room. In addition, the control and interlock system allows the remote control of the power converters from this control room.

The new control and interlock system is composed of 18 local PLCs. One PLC for each converter manages the local faults and communicates through a Profibus fieldbus with the master PLC. Another PLC manages the 18 kV substation and reports local faults. The master PLC supervises the entire system, gives the real-time information from any part of the installation, manages the common parts of the main power converters and communicates with the HP-UX based gateway. One Profibus fieldbus inter-connects all the 19 PLCs installed around the 7 km of the SPS ring. The HP-UX workstation runs a proprietary supervisor and acts as a gateway between the master PLC and the CERN controls network. This computer allows the project to be integrated into the architecture of CERN's accelerator and services control system. The implementation of the man-machine interface is based on Motif and X11.

### *2.5 Modernisation of the beam target electronics*

The aims of this project are the re-engineering of the SPS target electronics and associated controls and its integration into the existing CERN accelerator controls architecture. The objectives are: to replace obsolete home-made electronics, to homogenise equipment controls with industry standards, to carry out the project in collaboration with industry, to specify a configurable, modular, data and event driven solution, to provide low level equipment control and surveillance software, to specify the application interface layer, to integrate the equipment controller within the SL-EQUIP & SL-ALARM standard software packages [2,3] and finally to maintain compatibility with the present application, operation and expert programs.

This project, being the most recent one, will also be the most ambitious. It will make use of a new family of PLCs on the market that use open communication standards. A collaboration of equipment group experts and controls engineers will study and define a generic approach for integration of industrial systems in CERN accelerator control system.

Manufacturers are beginning to offer open PLC products with TCP/IP communication. For this project the new family of SIEMENS PLCs, type S7-300/400, has been selected. The challenge will be to integrate these PLCs from the network and from the equipment access point of view in an homogeneous fashion compatible with the existing infrastructure. We are considering porting CERN communication S/W into these PLCs or providing a communication gateway in between the central workstations and the cluster of local PLCs. Another technical verification is to check the bi-directional communication over multiprotocol network routers.

## **3 Interfacing issues**

For many years CERN has adopted TCP/IP as the communication protocol among workstations, servers and front-end computers. Accelerator and Services Controls

are fully implemented in the UNIX environment while the front-end computers run a UNIX compatible real-time kernel.

This has not been the case for industrial systems until recent years. Industrial systems need their own private network, run their special communication protocol, have their own real-time kernel and operating system, use their dedicated database and offer their proprietary controls and monitoring supervisor. All are justified for maximum performance, optimum investment and, to some extent, to be different from the competition.

### *3.1 Network connection of industrial equipment*

The connection of PLCs into an existing controls architecture can be done either at the network level or at the fieldbus level. The choice between these two options is made taking into account several factors: the communication openness, the inter-operability among different systems, the number of connections and their geographical distribution, the bandwidth required, the network protocol and the equipment control protocol to be used. The present experience of CERN's control engineers takes into account the evolution of the multi-protocol networking technology, the acceptance of TCP/IP for the communication with Programmable Logical Controllers (PLCs) and the emergence of new open DCSs proposed by manufacturers [4].

### *3.2 Homogeneous equipment access*

We discuss two aspects of equipment access. The first concern is the operator and end-user of the equipment and, in order to provide a good solution in that domain, the programmers' equipment access interface is also important.

The previous generation of industrial equipment employed at CERN was supplied with a dedicated operator console. These proprietary items were specific to the system concerned. As Unix and X-Windows have become more widespread the systems described in this paper all base the high level operator interface on these standards, although more specific interfaces for specialists may be found at lower levels. A final step, described below, is the integration of high level functionality from several of these systems into a single high level application. We believe that a seamless integration of a variety of these systems will be very important for the efficient operation of the beams in the LHC.

A homogeneous Application Program Interface, (API), to equipment remains an elusive goal at CERN. The two accelerator control groups have evolved different standards. The PS group [6] has a strict syntax which contains elements essential for the Pulse to Pulse Modulation of the CPS Complex.

For SPS and LEP the API, SL-EQUIP, evolved rather late [7]. Emphasis was on compatibility with lower layer calling protocols and ease of usage in order to encourage rapid acceptance. These aims have proved incompatible with the ideal of defining a common standard for all accelerators. The SL-EQUIP package hides details of the Control System from the client application program. All calls from application software follow the Master-Slave model.

SL-ALARM is a complementary package to SL-EQUIP which defines a simple API to the CERN Alarm System. Communication between industrial systems and external software for the operation of the SPS and LEP accelerators is based on the SL-EQUIP and SL-ALARM packages. To date the PS Complex has not addressed this issue.

More recently [1] a third approach has been introduced. This was driven by the goal of providing a fast, reliable, consistent interface to site services data in the CERN technical control room. The Technical Data Server (TDS) maintains a centralized image of equipment status that is updated on change of the monitored values. Built on the Talarian middleware package RT-Works all data entering the system passes through the generic RT-DAQ module. CERN has added a layer below this, the Generic TDS Equipment Access Protocol defining the interface to be respected by all systems. Initial experience implementing this interface with an existing DCS has been successful. Existing equipment entering the package uses SL-EQUIP on the equipment side of this layer. SL-EQUIP does not support an event driven approach so values must be polled here; however, the RT-DAQ module then implements a publish and subscribe approach. The TDS will achieve a single integrated high level interface to a variety of site services systems for the Technical Control Room at CERN.

A common API at CERN would facilitate software maintenance and provide a unique interface when dealing with external suppliers. At present a suitable standard to achieve these goals seems a long way off.

### *3.3 Industrial software integration*

Software developed to CERN specifications for use in the Control System has been fully integrated into the native software environment [8]. However, the approach with the more extensive systems described here has been the opposite. The external supplier has delivered the gateway computer and all system and application software. The intent is to establish clear responsibilities; the software supplied is isolated from the main body of application software.

We are currently reviewing our software configuration tools. One of the objectives will be to improve the integration of high-level gateways. A better control of the software environment would permit us to validate external software in a defined environment allowing CERN to supply the host computer and system for these interfaces.

In particular, it is important to fully control the inter-dependencies between industrial systems themselves and in-house software. We have used the SL-EQUIP and SL-ALARM packages for exporting the functionality of these systems upwards. The packages are supplied by CERN to the vendor who is then responsible for their integration into his environment. Taking the Machine Access system as an example the SL-EQUIP software runs in the HP-UX workstation. The server-side software of SL-EQUIP allows the Experimental Teams to give access from their general beam-line control programs. While all SL-EQUIP servers

can be traced through the Equipment Database a means of tracing their clients is missing in this system.

### 3.4 Global alarm retrieval

The CERN alarm system federates data from a wide variety of sources connected to the CERN Accelerator and Services Network. This facility has developed from the LEP Alarm System [9] which was built to manage the alarm messages arising from the LEP machine and the technical services. The role of this system has since been extended to the Technical Services for the whole of the CERN Site and the SPS Machine. Alarms are reported by a wide variety of systems and routed to a central server which sorts and dispatches them to various control rooms on the CERN site. A very important feature of the system is to be able to present, for example, the Technical Services operator with a single interface allowing him to see alarms from the various technical services at CERN such as electricity, water, ventilation, fire detection. The system can also provide a consistent chronology of important events involving several systems, cooling pumps losing their electrical supply is a simple example. During the early phases of this development, systems were integrated through the standard LEP architecture [10] connecting extensive DCS systems into the control system through a protocol converter attached to the MIL 1553 multi-drop bus. More recent systems inject alarms through the SL-ALARM package running in a UNIX workstation connected to the Machine and Services network. The workstation becomes the protocol converter and offers the manufacturer a powerful and familiar environment, which can also be used for other system components such as supervisory systems.

### 3.5 Specifications and project management [11]

To achieve a clean and well-managed integration of complex systems it is essential to define interfaces and responsibilities. For systems where the CERN network is used to communicate between components of the industrial system CERN supplies the communication service in terms of availability and bandwidth. In return the user, in this case the system vendor, must abide by certain restrictions. These are :

- 1) He must agree to the bandwidth consumed by his system;
- 2) He must only attach stations that can be managed by SNMP;
- 3) He must use the TCP/IP protocol or his own after prior agreement with CERN;
- 4) He must not make broadcasts.

For systems where the manufacturer inputs alarms to the Control System or where he exchanges services with other control systems then CERN provides the SL-EQUIP, SL-ALARM or RT-DAQ software. CERN remains responsible for this code while it is the manufacturer's task to interface his system. CERN prefers the manufacturer to supply the UNIX platform as part of his turnkey system and remain responsible for all hardware and software

running on that platform at least during the guarantee period.

## 4 Conclusions

For several years CERN has made a large effort to interface and to integrate industrial systems in its accelerators and services controls. Today all general technical services are industrial, either as complete turnkey systems or as individual clusters of PLCs. The integration practices are still evolving with the industrial offer; but TCP/IP and standard fieldbuses are becoming widely supported by industry. The new trend is to extend the use of industrial systems to pure accelerator controls for which dedicated equipment has always been designed and built in the past. Our future goal remains the smooth integration of industrial systems for the LHC operator.

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