IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Commissioning results of CERN HIE-ISOLDE and INFN ALPI cryogenic control systems

To cite this article: V Inglese *et al* 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **171** 012002

IOP Conf. Series: Materials Science and Engineering **171** (2017) 012002 doi:10.1088/1757-899X/171/1/012002

Commissioning results of CERN HIE-ISOLDE and INFN ALPI cryogenic control systems

V Inglese[1], M Pezzetti[1], A Calore[2], P Modanese[2], R Pengo[2]

[1]CERN, Geneva, Switzerland
[2]Laboratori Nazionali Legnaro, Padua, Italy

Vitaliano.Inglese@cern.ch

Abstract. The cryogenic systems of both accelerators, namely HIE ISOLDE (High Intensity and Energy Isotope Separator On Line DEvice) at CERN and ALPI (Acceleratore Lineare Per Ioni) at LNL, have been refurbished. HIE ISOLDE is a major upgrade of the existing ISOLDE facilities, which required the construction of a superconducting linear accelerator consisting of six cryomodules, each containing five superconductive RF cavities and superconducting solenoids. The ALPI linear accelerator, similar to HIE ISOLDE, is located at Legnaro National Laboratories (LNL) and became operational in the early 90's. It is composed of 74 superconducting RF cavities, assembled inside 22 cryostats.
The new control systems are equipped with PLC, developed on the CERN UNICOS framework, which include Schneider and Siemens PLCs and various fieldbuses (Profibus DP and PA, WorldFIP). The control systems were developed in synergy between CERN and LNL in order to build, effectively and with an optimized use of resources, control systems allowing to enhance ease of operation, maintainability, and long-term availability.
This paper describes (*i*) the cryogenic systems, with special focus on the design of the control systems hardware and software, (*ii*) the strategy adopted in order to achieve a synergic approach, and (*iii*) the commissioning results after the cool-down to 4.5 K of the cryomodules.

1. Introduction

The HIE-ISOLDE project is a major upgrade of the ISOLDE (Isotope mass Separator On-Line facility) and REX-ISOLDE facilities at CERN. The Radioactive ion beam EXperiment (REX) at ISOLDE has delivered beams with energies up to 2.8 Mega electron Volt per nucleon (MeV/u), using a normal conducting linear accelerator.

The High Intensity and Energy (HIE) ISOLDE project consists of an upgrade to higher energies up to 10 MeV/u, achieved mainly by replacing the accelerating structure by a superconducting linear accelerator (SC LINAC) composed of six cryomodules installed in series, each of them containing superconducting RF cavities and solenoids operated at 4.5 K. A new cryogenic control system was developed for HIE-ISOLDE by means of the CERN-UNICOS framework [1].

At Laboratori Nazionali di Legnaro (LNL), all the cryogenic control systems, and in particular the ALPI (Acceleratore Lineare Per Ioni) accelerator, are undergoing an important and radical modernization, allowing all the plants controls and supervision systems to be renewed in a homogeneous way towards the CERN-UNICOS standard. Before the UNICOS migration project started there were as many as 7 different types of PLC and 7 different types of SCADA, each one with its own particular programming language and operation interface. The complete migration is part of an agreement between CERN and INFN [2].

A joint effort was done for the realization of the control systems for HIE-ISOLDE and ALPI, which includes the realization of electrical cabinets according to cryogenic CERN standard, the PLC programming, the implementation of a supervision system and the commissioning of the plants.

2. The cryogenic systems

2.1. The HIE-ISOLDE cryogenic system

The HIE-ISOLDE helium cryogenic system [3] consists of a helium refrigerator connected to a dedicated cryogenic distribution line (Figure 1).

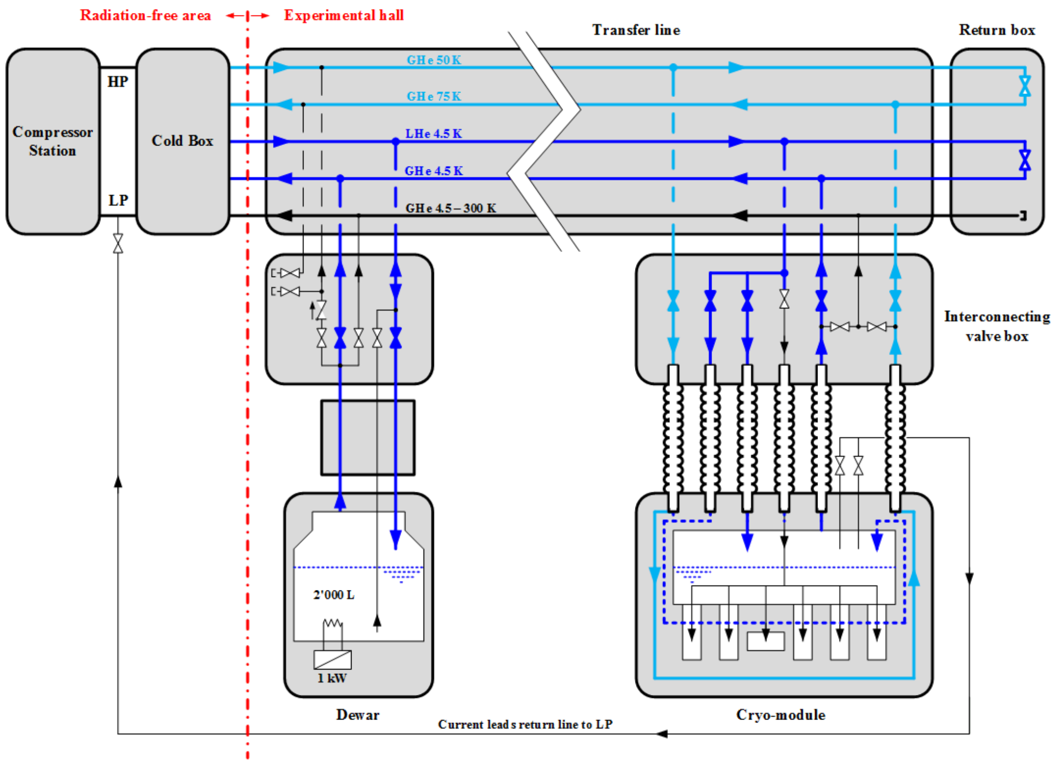


Figure 1. Simplified Piping & Instrumentation Diagram of one HIE-ISOLDE cryomodule.

2.1.1. The helium refrigerator. A helium refrigerator with a liquefaction rate of 1.5 g/s, manufactured by Linde Kryotechnik AG in the 1980's, has been refurbished, reinstalled and recommissioned to supply the cooling capacity required for the cool down of the cryomodules to 4.5 K.

Two screw compressors, mounted on the same motor shaft and working as two stages, provide a total mass flow of 156 g/s compressed from 1.04 bar abs up to 15.9 bar abs.

2.1.2. The cryogenic distribution line. A new 30-meter long transfer line, a 2000-litre storage dewar and six interconnecting valve boxes, have been built by Criotec Impianti Srl. The transfer line contains five cold pipes in the same vacuum vessel.

Each interconnecting valve box can provide independent feeding of the cryomodules and allows cool-down, warm-up, disconnection via bayonet connections and removal of individual modules.

The 2000-litre dewar has been installed to provide a cold buffer in case of refrigerator stop.

2.2. The ALPI cryogenic system

2.2.1. The helium refrigerator. The ALPI refrigerator (Figure 2) was built in the early 90s by Air Liquide. The plant is able to process up to 150 g/s of helium compressed to 16.0 bar abs. supplied from a compressor station, which consists of 4 units (two redundant).

In parallel to the Main Box Cold box, an "Auxiliary Cold Box" (ACB) is also installed to keep cold (around 80 K) the thermal shields of the cryostats in case of stop of the refrigerator. This is done to prevent that the thermal shields, warming up, would outgas the trapped impurities towards the superconducting cavities. The ACB consists of a cryostat containing liquid nitrogen in which a heat exchanger is immersed: the gas helium is cooled flowing through the heat exchanger by two circulators and pumped to the shields and back by two helium gas circulators in series. The mass flow in each pump is up to 100 g/s @ 6.5 bar with a Δp of 0.54 bar each.

2.2.2. The ALPI LINAC. The ALPI superconducting linear accelerator consists of superconducting quarter wave resonators. The LINAC consists of 22 cryostats housing a total of 74 superconducting cavities. The liquid helium is distributed as a two-phase fluid towards the cryostats in parallel. Each cryostat is connected to a valve box, which is placed in the main cryogenic distribution line.

3. Common methodology for control system implementation

The UNICOS (UNified Industrial Control System) framework has been used for the activities related to PLC programming and SCADA.

The cryogenic control systems for both installations include the realization, by means of a common methodology, of new electric cabinets according to CERN standard, PLC (SCHNEIDER-SIEMENS) programming, implementation of the supervision system (WinCC-OA), and commissioning of the plant. This methodology, capable of producing a PLC-based control and supervision system with

Figure 2. The top view of the ALPI refrigerator is shown, with its expansion turbines: the supercritical turbine is the one on the front.

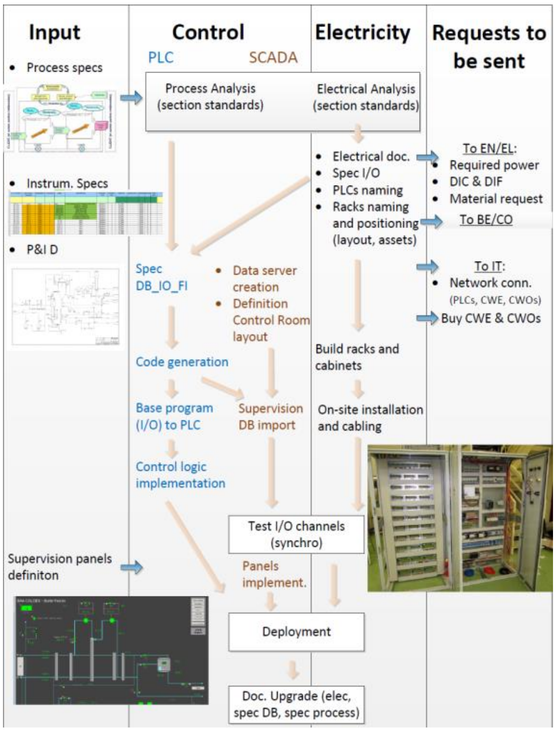


Figure 3. Methodology for control system implementation.

standard architecture and interface, has been used to achieve a high effectiveness in the production of the systems, for both hardware and software.

A strategy (Figure 3) including the following tasks has been conceived in order to develop the control systems [4]:

• Requirement analysis and review of the existing control system in case of revamping in order to define what the new system should do and to what extent the existing system (if there is one) needs to be modified. This analysis should include the whole system, from the instrumentation (field) to the operation (supervision) layer;

• Definition of the functional logic specifications of the system to be upgraded, including a graphical view of the process;

• Equipment naming definition according to cryogenic standard, in order to avoid the overlapping of different codifications used over the years;

• Technical study, namely the proposal of a solution to fulfil the requirements;

• Time schedule, resources allocation (manpower, production facilities, and costs), risk analysis, study of involved cryogenic subsystem and their inter-dependency. Particular attention has to be paid to the interconnections and exchange of information between old and new systems coexisting during the execution of a complete project;

• Preparation of the hardware (rack construction, instrumentation cabling, realization of the communication infrastructure) and software (implementation and debug of PLC programs, realization of supervision panels). Tools for virtual commissioning can also be prepared.

• Fieldwork, namely the installation at the final destination, deployment and commissioning.

UNICOS CPC (Continuous Control Process) version 6 was used to build process control applications from a well-defined library of generic objects.

The files automatically generated by the framework constitute the baseline of the PLC code and for the SCADA system.

The baseline code of the PLC has to be completed by particular part of code written according to the logic specification documentation. The baseline files of the SCADA system have to be finalized with the panels that constitute the user interface for the operators of the plant.

The last phase of the project is the commissioning of the plant. This phase starts with starts with the test of the I/O channels and is helpful to debug the code, in particular the interlocks, and to perform a fine tuning of the plant.

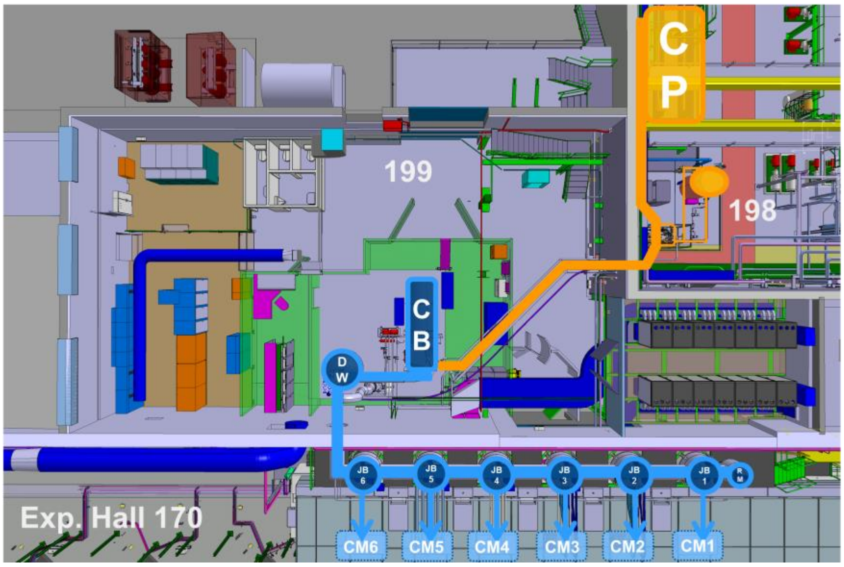


Figure 4. Layout of the HIE-ISOLDE cryogenic system.

4. The cryogenic control systems

4.1. The HIE-ISOLDE cryogenic control system

A new cryogenic control system, based on UNICOS CPC6, was design and realized for the HIE-ISOLDE installation (Figure 4).

The control system includes three PLCs: two Schneider Premium 5634M for compressor station and cold box, and one Siemens S7-317 for dewar, transfer line, six jumper boxes, six cryomodules, and one return module.

The three PLCs are connected to a total of 615 physical I/O channels. Table 1 details the number of channels for each of them.

In addition to that, Profibus DP, Profibus PA, and WorldFIP fieldbuses are integrated in the control system. In particular, Profibus is used: (*i*) for the connection of control valves, mass flow controllers, and pressure transmitters of dewar, transfer line, jumper boxes, return module, transfer line vacuum system (Figure 5), and (*ii*) for the connection of the cold box vacuum system (TPG 300 Pfeiffer unit with Profibus DP interface module).

Table 1. Physical I/O signals of the HIE-ISOLDE cryogenic control system.

HIE-ISOLDE	CPU	AI	AO	DI	DO
Compressor	1	62	14	98	30
Cold box	1	63	21	108	27
Dewar/line/cryomodules	1	8	1	133	50

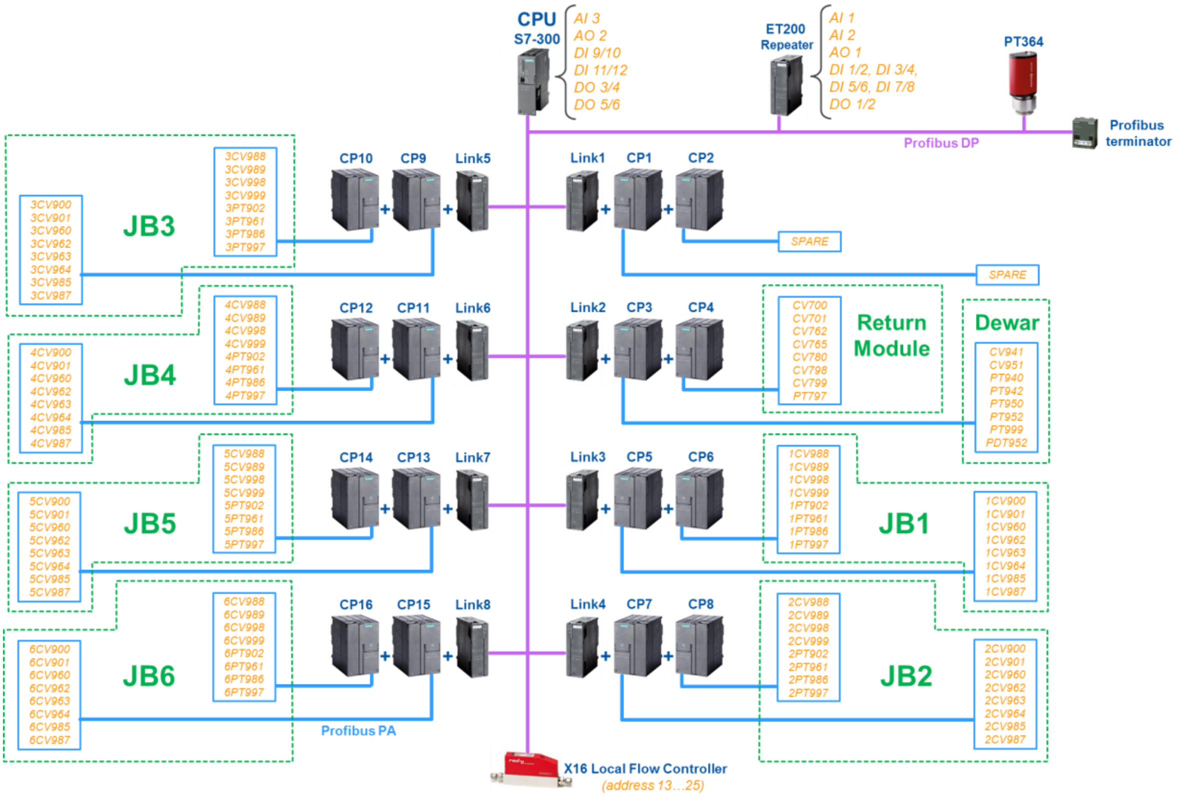


Figure 5. Profibus DP / PA connections for dewar, transfer line, jumper boxes, and return module.

The cryogenic control system is also connected, through a Front End Computer (FEC) to a WorldFIP bus used to connect the jumper boxes and cryomodules instrumentation. This bus was chosen for its suitability in radioactive environment, given that is has to withstand the irradiation coming from the linear accelerator (Figures 6). A total of 824 FIP channels are foreseen for the whole of the installation with six cryomodules.

4.2. The ALPI cryogenic control system

The control system was upgraded the first time in year 2000, from the old Syclope Z80 PLC to a more modern industrial PLC, the Eurotherm PC3000. Today this PLC is obsolete and no replacement parts are available: also the program needs to be totally revised because of the many "patches" added during the past years. The PC3000, consists of 4 racks and a single CPU, which are connected to the all I/O signals (Table 2). The vacuum system of the Cold Box, and the purging and vacuum system of the transfer cryogenic lines will be integrated, in the new control architecture, to the Cold Box, internal purifier and the transfer lines. At the moment each compressor has its dedicated control system (table 2) and their logic will be integrated in the cold box PLC.

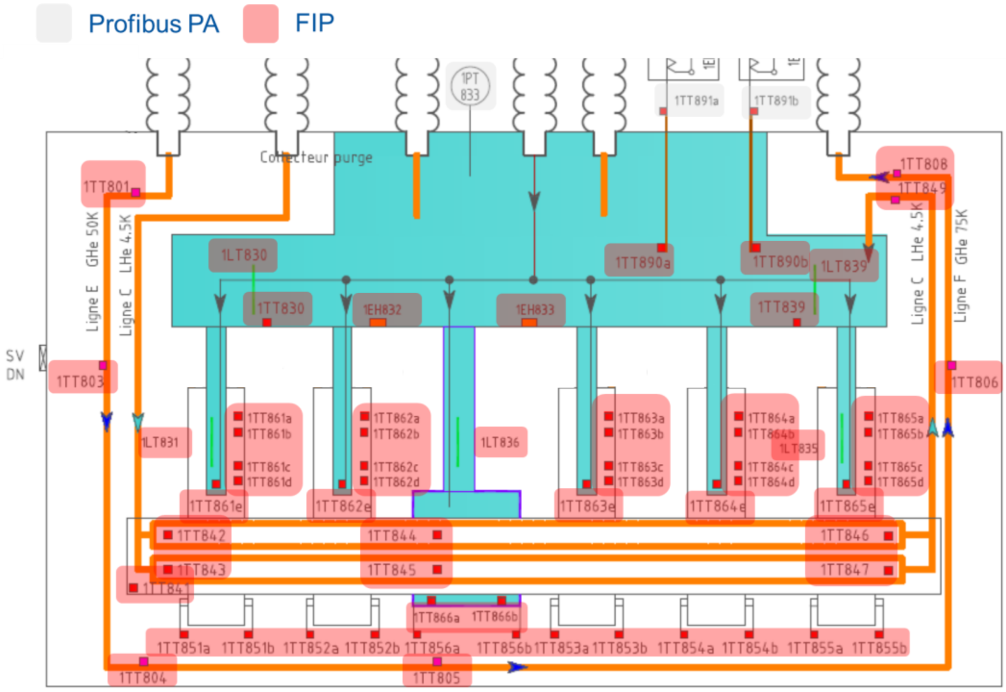


Figure 6. Instrumentation of a HIE-ISOLDE cryomodule.

As far as the LINAC is concerned, each cryostat is locally controlled by a logic unit/CPU that is connected to the field I/O signals (Table 2). These units are connected via RS485 serial signal to a concentrator which in turn is connected to two PC via ISA BUS, where is running a QNX v.2.2 operating system. This old system has been working for 20 years and has proven to be very reliable and functional. However today it is obsolete and must be replaced with a new one. It is no longer possible to find other spare parts or repair.

The project of UNICOS migration the cryostat control system has then the highest priority and the first prototype with UNICOS for the first group of cryostats has already been realized. The new project follows the line marked by the old system, maintaining almost the same architecture. A single PLC will control up to 5 cryostats, and the same configuration of electrical panels is maintained and it will be completely replaced by new ones. The Schneider Premium PLC and the panels of the supervisor with WinCC-OA is used with UNICOS CPC 6.

Table 2. Physical I/O signals of the ALPI cryogenic control system.

ALPI	CPU	AI	AO	DI	DO
Cold box (old system)	1	101	20	28	96
Cold box (new system)	1	140	30	72	150
Auxiliary cold box	1	12	2	32	16
Cycle compressor	4	32	4	120	112
LINAC cryostats	6	390	200	770	770

5. Commissioning results

5.1. The HIE-ISOLDE commissioning

After achieving stable operation of the helium refrigerator, the first cool down of the first cryomodule started in June 2015 and followed the sequence implemented in the control logic. Figure 7 shows, as an example, a supervision panel realized for one cryomodule.

The first step was the cool down of the thermal shield, in order to reduce, through cryo-pumping, the risk of contaminating the RF cavities. The following step was the cool down of supporting frame and helium reservoir to 90 K. Finally, liquid helium was provided in order to fill the reservoir (Figure 8).

Steady-state operation at 4.5K was reached and the first the radioactive beam at 4.0 MeV/u was successfully delivered in October 2015.

The second cryomodule will be installed and commissioned in the HIE-ISOLDE tunnel by May 2016. The assembly of the third and fourth cryomodules are expected to be completed in 2016.

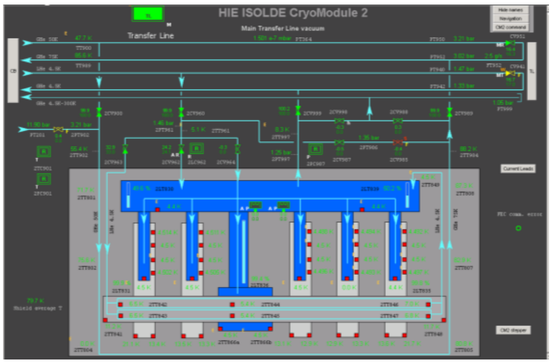


Figure 7. Supervision panel for the HIE-ISOLDE cryomodule.

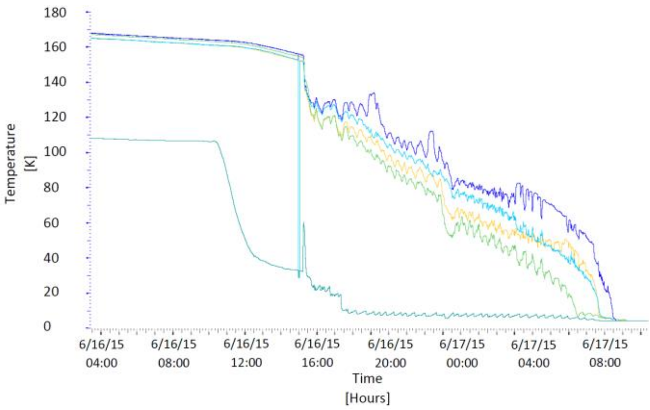


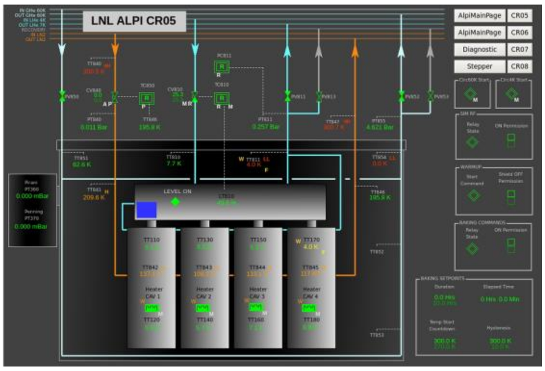
Figure 8. Cool down of HIE-ISOLDE cryomodule to 4.5 K.

5.2. The ALPI commissioning

Given the similarities of the two installations, the commissioning of ALPI was carried out following a procedure similar to that discussed in the previous section for HIE-ISOLDE.

The 13 cabinet, one for two cryostats, were synchronized i.e. all the signals were checked to correspond to the correct sensor and or transmitter, hardware/software interlocks and communication with other ancillary systems were also checked. The cool-down was carried out by sending, from the ALPI refrigerator, gas helium, at 6 bar around 70 K, to the thermal shield.

The gas at the outlet returned to the cycle compressors or to the intermediate stage of the refrigerator according to its temperature, until the shield was cooled to the 80 K level. Then liquid helium (LHe) at 1.3 bar abs was slowly sent to the LHe reservoir inside the cryostat (Figure 9) until it condensed at its bottom. Droplets of LHe then cooled the cavities by gravity, top part first, then the lower part (Figure 10) until all cavities attained the 4.5 K temperature. The PID regulator of the inlet control valve maintained the level at the given set point in steady state and for each individual cryostat.



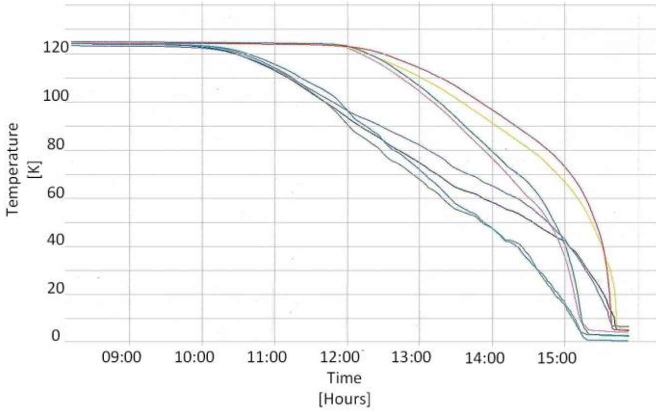


Figure 9. Supervision panel for the ALPI cryomodule.

Figure 10. Cool down of ALPI cryomodule to 4.5 K. The upper curves refer to the bottom part of the cavities while the lower curves refer to the top.

6. Conclusions

The UNICOS framework was successfully used for the realization of the cryogenic control systems for HIE-ISOLDE at CERN and ALPI at LNL. The framework allows a homogenization and simplification of the software production sequence corresponding to the two upper layers of a classical industrial control application. Both projects ended with the successful commissioning of the plants.

Additionally, the migration towards the CERN UNICOS standard offers the possibility to face a very important and necessary renewal work at LNL, with a relative modest investments in terms of economical and human resources. The result will be a single control system with a single supervision, following codification and nomenclature standards, for the whole of LNL cryogenics. This will be achieved in the next few years.

Acknowledgements

The authors would like to thank N. Delruelle, S. Martin, B. D'Hulster, A. Toral-Diez, B. Fernandez-Adiego, J. Casas-Cubillos, N. Trikoupis, J. Metselaar, and J.M. Chaverou from CERN. They would also like to thank T. Contran, A. Friso, and M. Pengo from INFN-LNL.

References

[1] J. Casas-Cubillos, P. Gayet, P. Gomes, C.H. Sicard, M. Pezzeti, F.J. Varas, *Application of object-based industrial controls for cyogenics*, EPACS, Paris, France, 2002.

[2] P. Modanese, A. Calore, T. Contran, A. Friso, M. Pengo, S. Canella, S. Burioli, B. Gallese, V. Inglese, M. Pezzetti, R. Pengo, "Cryogenic Control Systems Migration and Developments towards the UNICOS CERN Standard at INFN", *ICEC/ICMC 2014 Conference*, University ot Twente, Eschende, Netherlands, 7-11 July 2014.

[3] N. Delruelle, V. Inglese, Y. Leclercq, O. Pirotte, L. William, "Commissioning of the helium cryogenic system for the HIE-ISOLDE accelerator upgrade at CERN", *CEC-ICMC 2015*, June 20 -July 2 2015, Tucson, Arizona.

[4] V. Inglese. M. Pezzetti, E. Rogez, "The CERN revamping project of the obsolete cryogenic control systems: strategy and results", *Proc. of the CEC-ICMC Conference*, Spokane Washington, USA, 13-17 June 2011.