PROCOS: A REAL TIME PROCESS SIMULATOR COUPLED TO THE CONTROL SYSTEM

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Abstract

The paper presents the design of a simulator of a large-scale control system for the cryogenics of LHC and presents the results obtained. The simulator follows the real system architecture and is therefore made of a number of components sharing data through a standard protocol. The modeling of the process makes use of EcosimPro, the commercial simulation software for industrial systems. Each cryogenic component is represented by a set of Differential-Algebraic Equations; helium properties are obtained from a specialized library. The control system is simulated with a PLC-simulator running the process control logic implemented for the cryoplant. These are then connected to the same SCADA system used to operate the cryogenic plant. Thus, both the actual control policy and the supervision systems are reused during simulation. The objectives of this work were threefold: first, to provide tools for operators training, second, to test new control strategies before their implementation and third, to improve our knowledge of the behavior of the cryogenic systems.

INTRODUCTION

All CERN cryogenic systems are controlled by an industrial control system made of Programmable Logic Controllers (PLC) and a commercial SCADA system with the addition of the CERN multilevel Industrial Control System framework UNICOS[1].

The properties of helium, the large number of correlated variables and the wide operation ranges of the cryogenic plants make their control very complex. Up to now, the design and the control of the cryogenic systems were based on experience (both CERN and suppliers) of the process and on static calculations.

However, due to the complexity of the present system (coupled processes, nonlinear evolution, propagation and transport phenomena), dynamic simulations are the only way to obtain information of the real system behaviour during transients and to validate complete cooldown scenarios. Therefore, the team in charge of the LHC cryogenic Control systems decided in 2006 to develop a simulation tool connected to the actual control architecture.

Beyond this, the other main objectives of this work were:

- Offer a platform to train cryogenic operation crew offline.
- Allow the virtual commissioning and the optimization of new or upgraded cryogenic systems.
- Test new control strategies to improve the overall performance of complex processes without impacting the LHC up-time.

PROCOS

The solution which was developed, PROCOS which stand for PROcess and COntrol Simulator, is a set of interconnected components.

The simulation environment replicates the real control architecture and reuses many components present in the real control system (see Fig.1).

- The Supervision Layer reuses largely the CERN standard SCADA System PVSS II®.
- In the control layer the PLCs are replaced by PLC simulators (software packages).
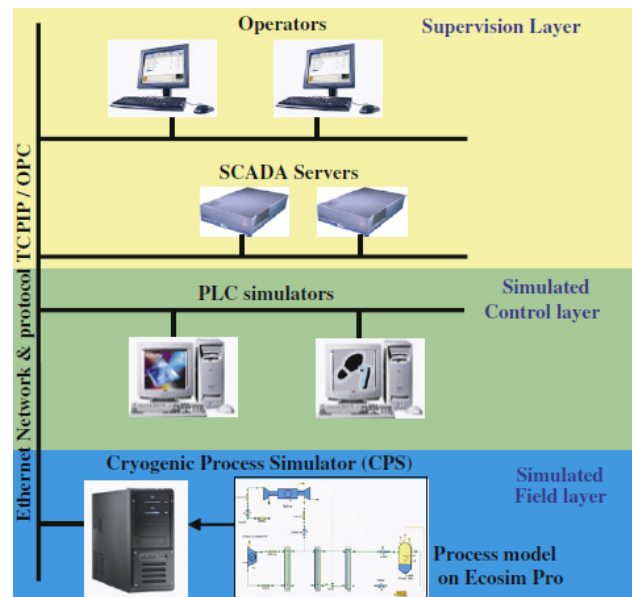- The real process is replaced by a Cryogenic Process Simulator (CPS).

Figure 1: The PROCOS structure.

At the supervision layer the necessary modifications were limited to the communication protocol with the control layer: the standard event driven protocol between the PLCs and the SCADA was replaced by OPC (OLE for Process Control) as it is the only protocol supported by PLC simulators. The UNICOS generation tools were adapted to produce automatically the data exchange configuration files.

At the control layer where the real process is controlled by PLCs, PROCOS reuses the existing PLC codes loaded in a PLC simulator provided by the PLC manufacturer and running on PCs. In addition, the actual I/O connections were replaced by an OPC interface between the PLC simulator and CPS, the process simulator.

The main task was indeed on the process layer. EcosimPro, a commercial modelling and simulation software (EA International), was used to model the CERN

cryogenic process. The PLC simulator gives orders (i.e. new values for actuators, mode changes, etc.) to the process simulator, which in turn finds the solution of the model and presents new values of the process sensors to the PLC simulator at the next sampling time.

PROCOS is built like the real process control architecture and includes the supervision environment. The process and the control duties are simulated separately and synchronized. This allows the simulation of large-scale systems on several computers by decoupling the main parts of a plant like it is in the field where the control logic is implemented in several PLCs.

CRYOGENIC PROCESS SIMULATOR

EcosimPro allows to model cryogenic systems by using an object-oriented approach where each cryogenic component is described by a set of Differential-Algebraic Equations (DAEs).

A complete cryogenic components library was developed. The component models, which were validated independently, are divided in five main categories:

- *Storage components*, such as ducts, phase separators, etc.
- *Hydraulic components* imposing a mass flow, such as valves, compressors, turbines, etc.
- *Thermal components* that can be composition of the two above with the addition of heat transfer, heat exchangers, heaters, etc.
- *Interface components* to connect the simulator to the control system.
- *Control components* to perform control action in the simulator.

Material properties are calculated as functions of temperatures using some empirical formulations. Helium properties are obtained from the specialized helium library HEPAK off-line and then integrated in the simulator to increase the simulation speed: interpolations performed in tables are 5 times faster than using directly the online library.

All the cryogenic plants, which were modelled, are large-scale cryogenic systems. The number of equations is proportional to the number of objects: the complexity of the model is directly proportional to the number of the heat exchangers (HXs) and of the turbines. A cryogenic plant containing more than 5 heat exchangers and more than 2 turbines generates around 1500 DAEs; this corresponds to a helium refrigerator with a refrigeration capacity of 400 W at 4.5 K.

Until now five types of cryogenic systems have been modelled:

- the CERN central helium liquefier,
- three 4.5 K refrigerators used to cool down
  - the magnet test benches (400 W),
  - the CMS magnet (1.5 kW)
  - the each one of the eight LHC sectors (18 kW
- one refrigerator at 1.8 K to cool the LHC magnet cold mass.

Table 1 gives the performances of the modelled systems. The simulator is generally faster than real time. Nevertheless, real-time is not reached for the 4.5 K refrigerators of the LHC sectors because of the large number of coupled equations generated by heat-exchangers.
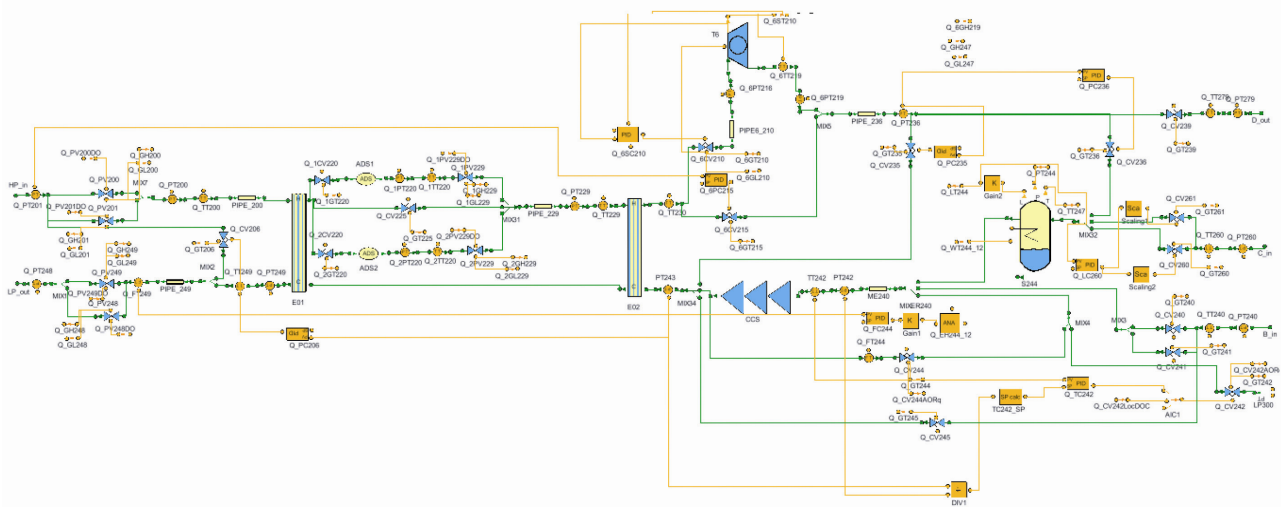

Figure 2: Example of a cryoplant model (1.8K LHC) with Ecosim.

Table1: Main Properties of Simulated Cryogenic Systems

System	DAE	Derivative variables	Simulation Speed*
Central helium liquefier	2063	170	x18
Test benches refrigerator	2268	194	x15
CMS cryoplant	3334	296	x8
LHC 1.8 K cryoplant	3056	249	x83
LHC 4.5 K refrigerator	4677	392	x0.5

SIMULATION VS REAL SYSTEMS

Figure 3 shows the simulation of a CMS refrigerator cooldown and the actual cooldown which took place in 2007 [2]. The results are excellent in terms of dynamic behaviour and precision; the same quality of results was observed in other simulations detailed in [3] and [5].
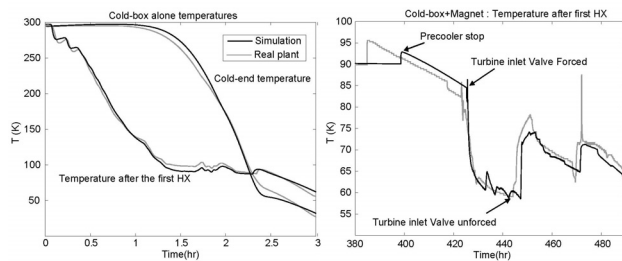

Figure 3: Simulation vs real cooldown of CMS cryoplant.

PROCESS IMPROVEMENT

Improvements of the control of the high pressure in the LHC 18 kW @ 4.5 K refrigerator were developed using the system and tested [4]. First, the PI high pressure controller was replaced by an Internal Model Controller (IMC) which shows a better stability on pressures and a better disturbance rejection using a feed-forward action. A floating pressure control was also designed by using a cascade control, and the different PI controllers were tuned from dynamic simulations. This proves that the use of the IMC controller for the HP allows a faster and a smoother control.

This type of studies that imply the use of system identification and process manipulation cannot be performed on a real plant. Dynamic simulators are then the only tool to elaborate and to demonstrate the efficiency of such controllers**.**

CONCLUSION

The PROCOS components suite for cryogenic systems is now operational and has been used successfully to model optimize and commission several cryogenic systems at CERN. It will now be used to train the operation crews [7]. Two main challenges are still ahead of us:

- modelling developments must be made faster and easier
- for large systems, optimization are still necessary to reach acceptable simulation duration.

New feature will be introduced in the CERN generation tools to cope with this.

New control system developments to other infrastructure system at CERN now justify the extension of the simulation capabilities of PROCOS to other types of continuous systems.

ACKNOWLEDGMENTS

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