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FIRST STEPS IN AUTOMATED SOFTWARE DEVELOPMENT APPROACH FOR LHC PHASE II UPGRADES CO_2 DETECTOR COOLING SYSTEMS

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Abstract

In the context of the development of a new class of movable, medium size, evaporative CO_2 cooling systems, the EP-DT group at CERN has designed and prototyped the systems Light Use Cooling Appliance for Surface Zones (LUCASZ). The use of Schneider M580 PLC with Ethernet IP distributed Inputs/Outputs (I/Os) and automated software generation tools is the novel approach which is essential for multiple unit production. The paper describes how the selected software and controls hardware concepts, used for the control system of this new class of units, will be implemented as baseline solutions for the CO_2 cooling systems for Phase II upgrade of ATLAS and CMS silicon detectors. The main challenges for future control system development will come from the number of cooling plants, the modularity requirements for production and operation, and the implementation of the backup strategy requested by the detector operation constraints. The introduction of automated software generation for both PLC and SCADA is expected to bring a major improvement on the efficiency of the control system implementation. In this respect, a unification step between experiments is highly required, still without neglecting the specific needs of ATLAS and CMS.

INTRODUCTION

The LUCASZ [1] CO_2 cooling plant, designed for detector testing, is a movable system that uses the so-called I-2PACL concept [2]. I-2PACL stands for Integrated 2 Phase Accumulator Controlled Loop. The I-2PACL cycle is very similar to a standard 2PACL (2 Phase Accumulator Control Loop) cycle [3], but the accumulator saturation pressure control is done via a single PID heater controller rather than by a split range PID controller. In other words, the accumulator cooling is done by the cold liquid supplied directly from the pump rather than by a branch from the primary chiller. The advantages of such configuration are a larger operational temperature range, a simplified design, reduced cost and programming simplification. The disadvantages are reduced cooling capacity and lower system efficiency.

To cope with the various detector needs, the LUCASZ system has been designed in two versions: LUCASZ^{full} Fig. 1 and LUCASZ^{lite}. The full version is equipped with a detachable LocalBOX, featuring two cooling loops and the dedicated control instrumentation to allow for multiple automated functionalities which facilitate the system operation for non-expert users.

The characteristics of distributed architecture, long term availability, modularity and small series of units were the driving factors for the selection of industrial controls hardware. Although the PREMIUM series of Schneider Electric, have been widely employed in similar projects at CERN, their commercialization will be discontinued and we have decided to identify an alternative family of products to be tested and validated.

Figure 1: Two LUCASZfull units at CMS.

CONTROLS

Controls Architecture

Each LUCASZ^{full} unit is composed of two major elements: the plant and the LocalBOX. In order to provide the maximum installation flexibility, the two parts might be kept together or physically separated. As an example, for one of the CERN CMS application, the CO_2 instrumentation is distributed over of about 20 m distance. The LocalBOX is kept inside the detector testing clean room and the cooling plant is placed outside, for noise reduction purposes and ventilation.

The master control cabinet showed on Fig. 2, located on the plant skid, is hosting the M580 Schneider Programmable Logic Controller (PLC) equipped with its own I/Os cards connected on the same backplane. The plant interfaces to the deported LocalBOX control cabinet are done via Ethernet IP filed network.

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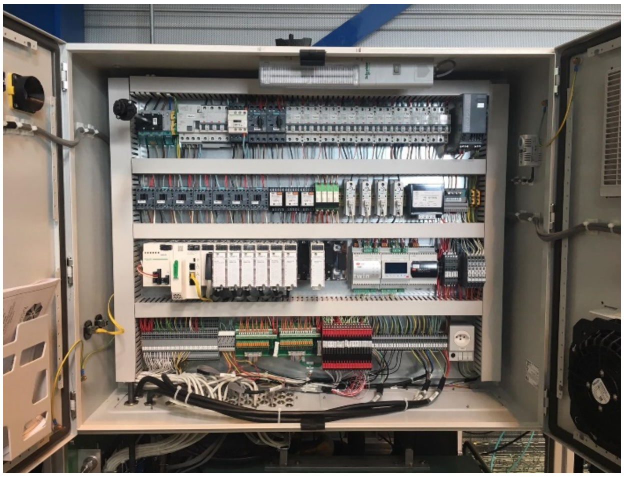

Figure 2: LUCASZ master control cabinet.

The LocalBOX hosts the distributed I/Os, connected via a Schneider CRA Ethernet RIO drop adaptor. The Ethernet IP based network between the PLC and the CRA is a private network, detached from the global infrastructure. Additionally, in order to facilitate the user operation, the LocalBOX is equipped with a local Schneider MAGELIS touch screen, featuring 22 operation User Interface (UI) panels, one of which is shown in Fig. 3. The HMI screens are designed to be as similar as possible to the main SCADA (Supervisory Control And Data Acquisition) system, both for the graphical representation and the navigation hierarchy.

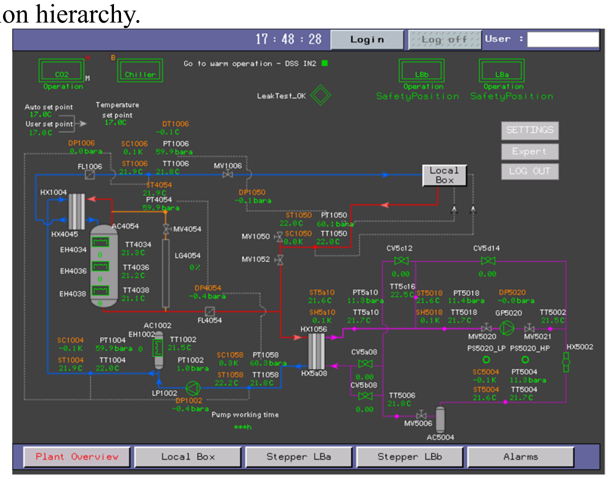

Figure 3: MAGELIS local HMI UI panel.

Both the PLC and the touch screen are placed on the CERN Technical Network (TN), physically detached from the outside world for security reasons. To improve the system reliability due to possible network failures the LUCASZ PLC and touch screen connect to the same fan-out.

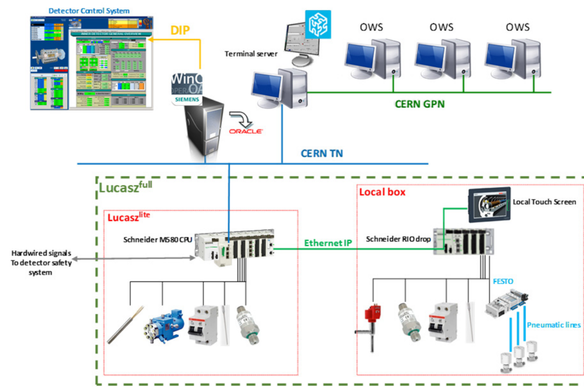

Figure 4: LUCASZ control system architecture.

The overall LUCASZ control system architecture scheme is presented in Fig. 4.

The control software for both the PLC and the SCADA conforms to the CERN UNICOS (Unified Industrial Control System Continues Process Control [4]) CPC 6 framework [5]. UNICOS is the baseline solution for all current and future detector cooling control systems at CERN, since it guarantees long term maintainability and a unified program structure across different applications.

Despite the small scale, the LUCASZ cooling unit is equipped with 152 I/Os. The PLC runs 13 control loops, 142 alarms and 668 UNICOS objects in total. The main user interface is based on Siemens WinCC OA SCADA. To provide the most accurate system diagnostic, 30 SCADA UI panels are available including: simplified master views for non-expert users, detailed P&ID (Process and Instrumentation Diagram) based views for cooling experts, alarms with detailed diagnostic (see Fig. 5), electrical diagnostic and steppers.

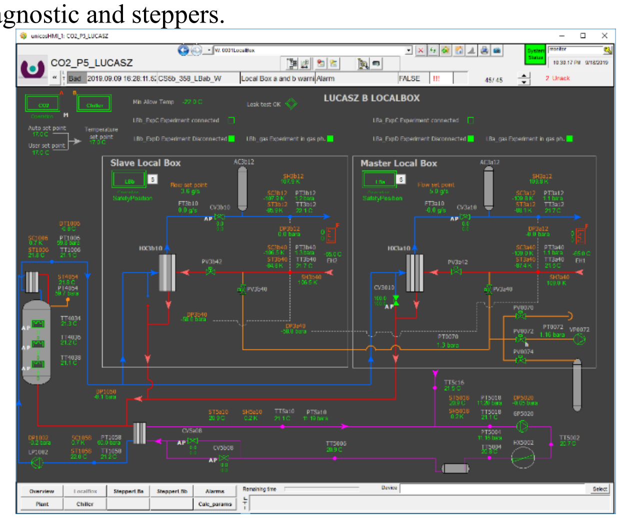

Figure 5: LUCASZ SCADA UI panel.

As the LUCASZ units are typically used for detector cooling, an additional communication path to the DCS (Detector Control System) has been established using DIP protocol with simplified structure. One-directional communication path is used to sends the most important cooling data to the DCS.

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Operability – PCOs, Sequencer

The process logic is organised in a hierarchical tree where the master is the CO_2 system PCO (Process Control Object). The master is the plant, hosting the core components. The children PCOs are belonging to the LocalBOX, which handles the operation of the two independent cooling loops. On each loop, a fully automatic and safe sequence for 3 operation modes is implemented: connection, disconnection and operation. The operation modes feature a dedicated sequencer that moves the system through different phases and transitions. Figure 6 presents the sequencer for one of the lines of the LUCASZ LocalBOX.

Automated Software Generation

All LUCASZ system's software are separately generated using CPC 6 UAB tools of CERN. This significantly reduces the time required for the software production and mitigates the possibility of human errors. Figure 7 presents the typical generation work flow.

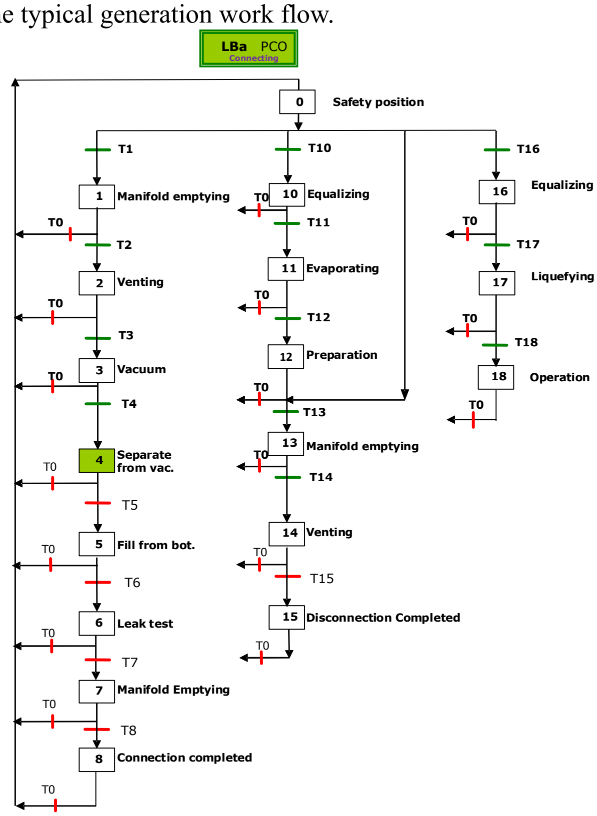

Figure 6: LUCASZ LocalBOX Line A sequencer.

The cooling control engineers prepare, based on the electrical schematics and the functional analysis documents, a specification file in XML format. The file contains all the UNICOS objects definition and relations required for the PLC and SCADA programming. For the first time ever in detector CO_2 cooling applications a set of dedicated Python templates has been prepared to generate automatically all the PLCs (four LUCASZ units) dependent logic, including, but not limited to, sequences, transition logic, calculated variable etc. The use of these templates, even if significant time was required for their preparation, paid off quickly during the small serial system production (5 units) after the first LUCASZ commissioning. During this activity indeed, the need of major logic refurbishment became clear. If the system logic generation wouldn't have been automated via the Python scripts, the narrow schedule between the first system commissioning and the next one would have not been met. The used templates, flexible and incorporating the CERN LHC Cryogenics experience [6], are today the baseline solution for all CO_2 detector cooling control system. This is a major step that brings us closer to an efficient and error free software production for multiple Phase II upgrade units of ATLAS and CMS silicon detectors, where up to 8 cooling systems will need to be operated in parallel. The templates are today the placeholder of the core knowledge and state of the art control technics required for efficient, stable and safe 2PACL CO_2 detector cooling.

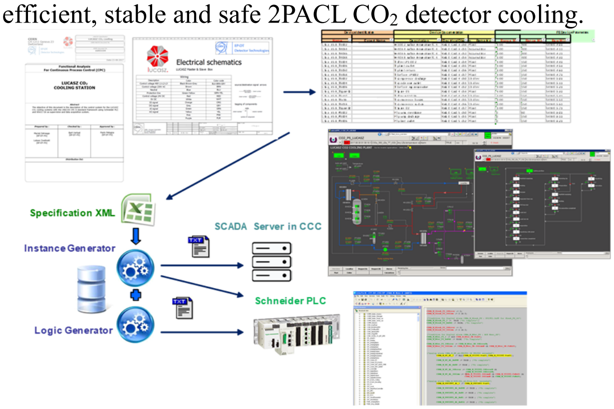

Figure 7: UNICOS CPC 6 generation work flow.

The different templates created for the LUCASZ system give the possibility to easily repeat the code generation for several similar calculations (e.g. SuperHeating calculation), thanks to a set of parameters which are embedded in the specification file. Templates give also the possibility to repeat a specific logic used on same UNICOS object into different system: e.g. freon injection valve before heat exchanger.

The multitude of solution provided by those templates will simplify in the future the code generation for known needed logic in CO_2 control system.

Specific Software Implementations

One of the specific software implementations in the LUCASZ system is the dynamic limiters for the accumulator's heater PID control loop. The accumulator is connected to the detector return line, is equipped with 3 electrical heaters and continuously cooled via the CO_2 pumped trough. The accumulator pressure control sets the saturation temperature in the vessel, which corresponds to the detector evaporation temperature. In most of the operation conditions, the heaters are stably controlled via PID loop; however, in order to cope with the extreme operation cases, like when the full load is suddenly applied, two dynamic limiters were introduced. One high limiter works as a function of the heater surface temperature, to avoid dry out (full evaporation of the CO_2 which may provoke overheating) and a second low limiter acts to avoid too low pump sub cooling (CO_2 flow stoppage). These limiters smoothen the

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CO_2 plant reaction to rapid changes and allow for continues operation of the system in all conditions.

Safety

The 2-phase CO_2 cooling is a high pressure system, where special safety precautions must be taken both for the cooling system itself and for the tested detector. As a first approach, the mechanical safety of the cooling plant must conform to appropriate standards (typically PED – Pressure Equipment Directive). The higher-level software alarms shall protect against all emergency scenarios and be always set to trigger before any hardware protection. Typically, for the 2-PACL CO_2 systems, a 3-level interlocking philosophy for the electrical haters must be applied.

The detector protection is established via hardwired positive logic electrical signals exchanged between the LUCASZ system and the Detector Safety System (DSS). Typically like: plant – stopped or started but no cooling power delivered to the detector or go to warm DSS command.

Commissioning Issues and Lessons Learnt

One of the main issues with technological choices we made for the LUCASZ system was the incompatibility with WAGO Ethernet IP couplers of early generation. It is impossible to establish bi directional communication with WAGO cards if not using the latest couplers with M580 class PLCs. Moreover, if multiple people work on PLC programming the Schneider software must always be equipped with exactly the same EDS configuration file for third party devices. Using different EDS files from non-Schneider manufacturer but with same version release creates incompatibility in the Unity Pro library (Unity Pro being PLC program software for Schneider)

Another point to be mentioned is our observation that MAGELIS local touch screens cannot operate within internal private network of Ethernet IP. They must be connected to same ethernet network as PLC.

CONCLUSION

This little series of LUCASZ CO_2 units is equipped with the newest Schneider PLCs available on the market and with Ethernet IP based distributed I/Os technology. Despite small incompatibility issues with some third-party devices, the selected distributed architecture proved to be a good baseline hardware configuration, fulfilling all the requirements of the future CO_2 detector cooling systems for the Phase II upgrades of LHC detectors. The automatic code generation based on Python templates will be further developed to cope with the strict requirements of the large systems of the future ATLAS and CMS experiments cooling systems.

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