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AN EVALUATION OF SCHNEIDER M580 HSBY PLC REDUNDANCY IN THE R744 SYSTEM A COOLING UNIT

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Abstract

The Detector Technologies group at CERN has developed a 2-stage transcritical R744 cooling system as a service for future detector cooling. This is the first system in operation at CERN where Schneider HSBY (Hot Standby) redundant PLCs are used. This cooling system provides a good opportunity to test the Schneider redundant PLC system and understand the operation, limitations and probability of failure in a controlled environment. The PLC redundancy is achieved by connecting Schneider M580 HSBY redundant PLCs to the system where one is the primary which operates the system and the other is in standby mode. A series of tests have been developed to understand the operation and failure modes of the PLCs by simulating different primary PLC failures and observing whether the standby PLC can seamlessly take over the system operation.

INTRODUCTION

Previously, most large-scale systems at CERN have made use of multiple small PLCs where there is one running per subsystem and communicating with one leading PLC. The idea behind this is that if one PLC fails, the other subsystems are still able to operate. However, in previous experiences, losing one subsystem can cause erroneous readings fed to the other subsystems or interlocks created in the processes of the other subsystems.

In the context to avoid multiple semi-autonomous PLCs, EP-DT decided to go in the direction of a central powerful PLC connected to the different subsystems which each have communication cards that read and write inputs and outputs. This ensures the centralisation of information inside a single core element. In order to improve the communication availability of such systems the RIO loop was proposed following ring topology. This has been used in the MAUVE system with good results. The ring topology used is shown in Fig 1.

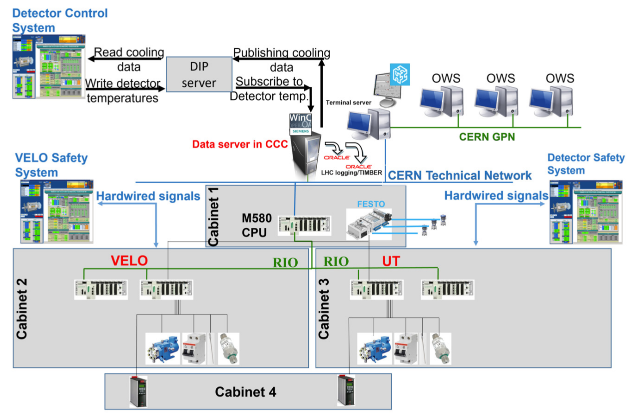

Figure 1: MAUVE control architecture.

For the LHC Phase II upgrade, two different cooling systems, CO_2 based, will be installed, namely the R744 Primary system (2 stages transcritical) [1] and the 2PACL (2 Phase Accumulator Control Loop) system [2], both of which are quite large with a high quantity of inputs and outputs.

The approach of a main core system to control the different remote IO was foreseen to be used in Phase 2. However, following recent technological developments by Schneider, the solution of PLC redundancy was proposed to improve the reliability of the system. Before installing the systems underground, this solution was first implemented on the surface with R744 Primary System A which is currently operational. Following this, it will also be used in the DEMO system which is a 2PACL equivalent currently being installed. The purpose of these surface systems is to gain experience on the process and validate the redundant architecture before installing the final systems underground.

CONTROLS

PLC Selection Following Current Solutions Available on the Market

The Schneider M580 HSBY redundant PLC was chosen for these systems due to satisfactory compatibility with the currently used UNICOS (Unified Industrial Control System [3]) framework as well as the simplicity of implementation. CERN makes use of mostly Schneider and Siemens PLCs, with Schneider being the most commonly used PLC in cooling applications. PLC redundancy has previously been implemented at CERN using Siemens PLCs (S7-400). However, the return of experience from our cryogenics colleague experts was giving a global difficulty with implementation and possibility to update code. There is a new type of PLC from Siemens which proposes a redundant

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functionality. However, these PLCs (1500 generation) use dynamic addressing which is currently not the simplest to implement with UNICOS framework as this last one is establishing a link between PLC and SCADA through fixed addressing. This leads to a need of global update on both SCADA and PLC for any simple operation. The Schneider redundant PLCs used in the new systems are much simpler to maintain and program using the CERN environment.

From the Electrical System Configuration to the Control System

Following the idea of improving the reliability and availability of the cooling systems, several decisions have been made in terms of electrical distribution and control systems. After performing an analysis of critical equipment, the most important elements are connected to a UPS (uninterrupted power supply) to avoid system failure during loss of power. To ensure circulation of CO_2 for example, the liquid pump creating the flow in the system is under UPS.

It is also critical to keep the 24VDC circuit operational. The approach here is to use two redundant power supplies, interconnected through a redundancy module, with one power supply under UPS. The configuration of the system can be seen in Fig. 2 below.

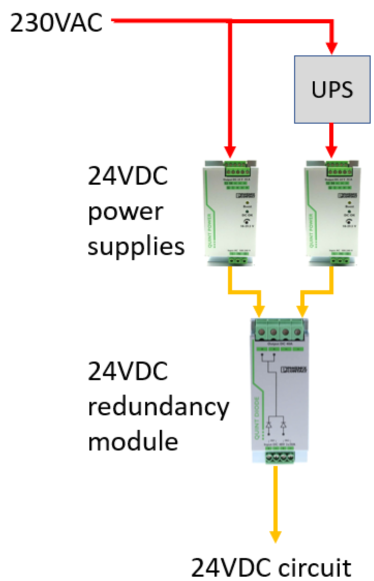

Figure 2: 24VDC Redundant power supply configuration.

The benefit of this configuration is that the failure of one power supply does not cause a loss of power to the 24VDC components and signals, meaning that we keep the monitoring possibility of the system and can monitor and track the current process even in case of interlock. This is needed for system diagnostic to understand the process state at any time.

Similarly, the use of redundant PLCs aims improve availability by removing the single point of failure found in single PLC applications. The system has two backplanes with two separated PLCs. Each PLC has its own communication card which communicate with the CERN Technical Network. Risk of failure is decreased by powering each PLC with its own dedicated redundant 24VDC power supplies. The configuration of the redundant PLCs used in the R744 Primary System is shown in Fig 3.

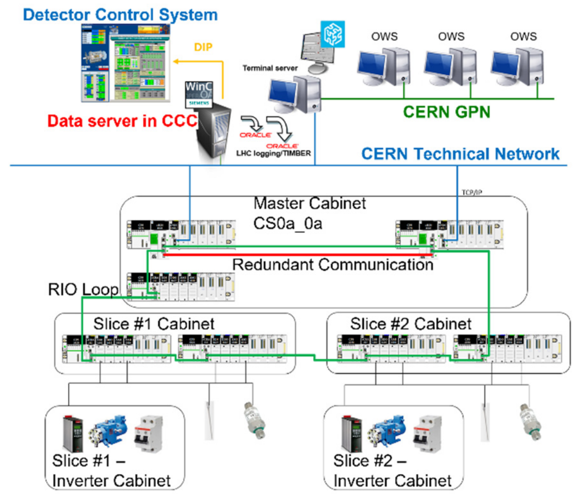

Figure 3: Topology of PLCs in R744 Primary System.

The green connections represent the RIO loop which exchanges data between backplanes. The red connection between the two PLCs represents the Hot Standby link which sends application variables, system status and I/O data from the primary PLC to the standby PLC. It is also used to compare the code program stored in each PLC [4].

The PLCs are named PLC A and PLC B, either one receives the role of primary PLC and standby PLC. This depends on several parameters such as which PLC was loaded first, internal logic comparison, and the state of the PLCs.

Both PLCs run the same program, with one acting as the primary PLC which operates the system and the other acting as the standby, ready to take over should the primary PLC become unavailable.

Additionally, efforts have been made to reduce errors in the system by using automatic code generation [5]. There are many basic and complex functions that are needed several times in each project, such as addition, subtraction, and saturation temperature calculations. Templates are written with the logic for each basic function and are then used to generate multiple similar functions where the PLC developer needs only to specify the names or values of the input variables for each instance. This way, the function is written once and can be used to generate as many iterations of the function as required. This reduces the likelihood of syntax errors which are common when developing code.

Failure Modes

The Schneider HSBY redundant PLCs have already been installed in the R744 Primary System A and this system was used to test the various failure modes of the PLC, power supply, and communication with the technical network and remote IO backplanes. It is important to understand how the system operates under different combinations of failure modes and whether the system can still run under these circumstances. The results of these tests are summarised in Table 1. In these tests, a PLC failure is

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defined as any loss of PLC operation, whether due to a failure on the power supply, a circuit breaker tripped, or a failure within the PLC itself.

Table 1: PLC and System Response to Multiple Failure Modes

Failure mode	PLC A	PLC B	System Response
1. PLC B failure	Primary	Off	Running
2. PLC A failure	Off	Primary	Running
3. Failure of both PLCs	Off	Off	Not running
4. PLC A loss of network communication	Standby	Primary	Running
5. PLC B failure & PLC A loss of network communication	Primary	Off	Running, no network communication
6. PLC B loss of network communication	Primary	Standby	Running
7. PLC A failure & PLC B loss of network communication	Off	Primary	Running, no network communication

In addition to the failure modes shown in Table 1, there are failure modes which result in more complex PLC and system behaviour. These cases are described in detail in Table 2.

Table 2: PLC and System Response to Complex Failure Modes

Failure mode	PLC Behaviour and System Response
8. Logic of PLC A different to PLC B	The PLC which is initially primary remains as such and the other PLC is in wait mode. The system operates without error.
9. Loss of one link between backplanes	The primary and standby PLCs remain as they were, and the system operates as normal
10. Loss of multiple links between backplanes	The primary and standby PLCs remain as they were, but the system runs with loss of functionality. The backplanes which are completely cut off from the PLCs are inoperable.
11. One PLC is completely disconnected from the RIO loop, the other has no connection to the Technical Network, the Hot Standby link is still available	The PLC connected to the Technical Network becomes the primary and the PLC which is still connected to the RIO loop is in standby. In this case the system does not operate as the primary PLC has no communication with the remote backplanes

From the system responses seen in Tables 1 and 2, it is clear that the only failure modes that result in loss of system functionality or full system failure are when both PLCs fail or multiple connections in the RIO loop are lost.

In addition to reducing the likelihood of failure, changing the primary PLC from PLC A to PLC B happens seamlessly with no effect seen in the system.

The switching between primary and standby modes makes use of the default switching logic from UNICOS, however, the developer does have the freedom to define user-specific conditions for this change. For example, the R744 Primary System A will make use of user-defined logic to modify the scenario shown in point 11 of Table 2. In the case that one PLC is disconnected from the RIO loop and the other is disconnected from the technical network, the default logic would keep the PLC connected to the Technical Network as the primary despite its lack of communication with the other remote backplanes. This is not consistent with the reliability definition established for the Phase 2 upgrade. Instead, the system should have the primary PLC connected to the RIO loop while the PLC connected to the Technical Network should be in standby mode. In this case, there is no communication of system information to the network, but the system can still operate.

CONCLUSION

The Schneider HSBY redundant PLCs are a solution compatible with the Phase 2 cooling upgrade requirements in term of availability and reliability. Its implementation is supported by CERN UNICOS framework and specific automated generation for CO_2 templates developed by EP-DT. The introduction of PLC redundancy is defined as baseline for the LHC detectors' critical CO_2 cooling applications as an additional level of safety.

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