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ESS PLC CONTROLS STRATEGY

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Abstract

The European Spallation Source ESS AB is an accelerator-driven neutron spallation source. The Integrated Controls System (ICS) division is responsible for providing controls and monitoring for all parts of the machine (accelerator, target, neutron scattering systems and conventional facilities). Also, Accelerator Division, Target Division and other parts of the organisation will be deploying PLC Automation Systems. A large number of applications have been identified across all the facility where PLCs will be used: cryogenics, vacuum, water-cooling and fluid systems, power systems, and safety & protection systems. This work describes the different activities put in place and the strategy followed at ESS regarding PLC technologies. This strategy consists not only of the standardisation of a PLC vendor but also testing activities, generation of documentation and standardisation of other aspects (for instance, regarding installation). The documentation about PLC controls integration and standardisation and the approach to insert PLCs in the different controls workflows are described. Finally, the results of different tests (PLC timing correlation) are shown.

HARDWARE STRATEGY

The ICS division has deployed a hardware strategy based on the different types of applications expected in the ESS project. At the same time, a compromise is needed in order to keep the number of the different used technologies to a minimum, which ensures maintainability from a long term point of view. According, to this premises ICS has standardised three different types of technologies:

- **Fast, real-time signal processing**. In this category fall those cases that need state-of-the-art technology, a range of acquisition in MHz or GHz sampling rates, and FPGA-based processing in many occasions is included. For this type of applications ESS has decided to use the microTCA platform [1]. Currently, ICS is working in all the processes needed after the platform selection (firmware, software, operational procedures). This also, involves the selection of other technologies and standards like FMC (FPGA Mezzanine Card).

- **Middle-range I/O**. This segment is designated to fill the gap between the fast real-time I/O described above and the traditional industrial I/O solutions. In this segment, real-time requirements have still to be met but the requirements for data processing and transfer are less stringent. The ESS standard platform for this range of tasks is the EtherCAT [2] standard that uses regular Ethernet wiring but has a specialised protocol that enables tight time synchronization (kHz range I/O).

- **Industrial I/O**. Most of the systems that do not require tight synchronisation with the ESS accelerator cycles (14 Hz) are best served by programmable logic controllers (PLCs). PLCs will be considered when the built-in logic ensures safe operation of the device under control even if the connection to the upper layer (EPICS) is broken. Cooling systems, vacuum control, (slow) interlocks, etc., are typical examples of areas where PLC is an appropriate choice.

USE CASES

A large number of applications have been identified across all parts of the facility where PLCs will be used: cryogenics, vacuum, water-cooling, fluid and power systems, building management, safety and protection systems. They have common characteristics in terms of relatively long response for their control systems (tens to hundreds of miliseconds), standard industrial sensors and actuators, etc.

- **Cryogenic Systems**. ESS will own a number of cryogenic systems. The cooling power will be produced in 3 different cryoplants (Accelerator Cryoplant, Test Stand & Instruments Cryoplant and Target Moderator Cryoplant). A Cryogenic Distribution System will connect the cryoplants to the Accelerator, Target and Cryomodule Test Stand. The most important characteristics of these control systems (regarding PLCs) is that regulation-using PIDs will be needed. The I/O needed will be based on analog and digital acquisition. The protocols Profibus PA, Profibus DP and Profinet CBA, defined in the standard IEC 61784-1 will be extensively used, as the I/O needs to be highly distributed. Communication processors with serial interfaces may be also needed.

- **Vacuum Systems**. Vacuum Controls involve the handling of different types of signals, at different scanning rates and a great part of them at a suitable range for PLCs (<1Khz). Reading analog and digital signals from different gauges, controlling vacuum equipment with analog and digital signals (eg. mass flow controllers and gate valves) are the main use cases. In term of logic, PLCs will be mainly used for interlocks and maybe for implement states diagrams in order to control equipment.

- **Water-Cooling and Fluid Systems**. These are also typically industrial systems where the most frequent signals are analog I/O, digital I/O, PT100 temperature sensors and fieldbuses to distribute this periphery. From the logic point of view interlocking and regulation could be the major applications. Fluid Systems. Specialty

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Target Systems involve loops containing different gases (helium, nitrogen, etc.). Thermocouple temperature sensors, analog I/O for pressure gauges readouts and operation of valves or mass flow controllers will be typical examples of these applications. Regulation will be highly present in the control logic.

- **Power systems**. PLC based control systems in Power Supply Systems will be used for the Accelerator, Target and Neutron Instruments Systems. Different applications for substation automation for instance will be used. Different protocols (TCP, Modbus, ...) and analog and digital I/O will be the most used ways to interface the equipment. Voltage regulation is one of the most common types of logic implemented. Fieldbus technologies to manage distributed I/O will be also used.
- **Interlock/protection and safety systems**. These systems will be one of the big PLC consumers for the overall ESS facility. Local slow interlock system and the slow part of the Machine Protection System will be mostly based on PLC. Different types of CPUs (normal and high processing capabilities) will be needed. Serial, IEC 61784-1 protocols, analog I/O, digital I/O will be used. Some of those systems may be highly distributed so fieldbus technology may be intensely used. Also the Personal Safety System (PSS) will involve PLCs suitable for use in safety applications (safety PLCs, SIL 3 rated). The system will be based on the IEC 61508 Standard [3].

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The current estimation of PLC usage at ESS is shown in Table 1:

Table 1: Estimated Number of Units for PLC Hardware at ESS

Hw. Unit	**Qty.**
Mid. Range CPU	176
High Range CPU	38
Safety CPU	23
Digital Input Module	208
Digital Output Module	87
Analog Input Module	953
Analog Output Module	91
Analog Input T.Module	442
Profibus Module	100
Serial Module	720
Distributed IO chassis	326
Safety PLC Set	23
Safety Digital Input Module	85
Safety Digital Output Module	85

STANDARDISATION

Integrated Control System Division does not own all the PLCs at ESS. However, this division will provide the majority of the code development effort and it has the standardisation capability as almost all of them need to be integrated into the EPICS control system. As with other hardware technologies, the standardisation approach does not only consist on the selection of a provider or a type of technology. A comprehensive strategy is being developed in order to make the selected technology available to the user, provide documentation and support and achieve a time to deployment as short as possible. Only all these factors together can ensure that the users adopt standard technologies. The aspects taken into account are the following:

- **Vendor Selection.** This is the first step of the standardisation process. ESS has chosen to standardise PLC technology by procuring a framework agreement with a PLC vendor. This has already happened for applications related to safety and the tender for PLC vendor for the rest of the applications is in evaluation phase. Once the process is completed the Supply, Procurement and Logistics Division will create a catalog of PLC products making visible the different products available.
- **E2H2C.** The ESS Electronics Hardware Harmonisation Committee has the mandate of creating and managing a programme-wide electronics hardware recommendation list. A working group regarding PLCs was created inside this committee. This working group aims to be a centralised point of information for all the users of PLC technology in the organisation. This will permit to treat other aspect connected to the standardisation like installation, technology choices or know-how sharing.
- **Documentation** A set of documentation is in the process of being prepared. Three different guidelines are being prepared: (1) documentation describing the standard interfaces of any PLC to the control system; (2) PLC Programming Guidelines ; (3) Guidelines for PLC equipment selection.

PLC TIMING CORRELATION

The standardisation process has to be accompanied by a series of prototyping activities in the lab in order to solve operational problems that this technology may pose. This section describes one example, which explores a standard way to provide PLC synchronisation to all the users in ESS . The Integrated Control System will archive data from very different sources. A big part of the data will be acquired through the acquisition of different controllers, which can be directly synchronised through the ICS Timing System. Typically, PLCs synchronisation needs to done connecting the PLC CPU to a NTP Server. So, they cannot be connected directly to the Timing System in a straightforward way. The simplest possibility to provide an overall synchronisation for the PLCs is to configure the Timing System as the time provider for an NTP server. This NTP will provide overall synchronisation to all PLCs. To perform this activity, the following prototype in Figure 1 was designed.

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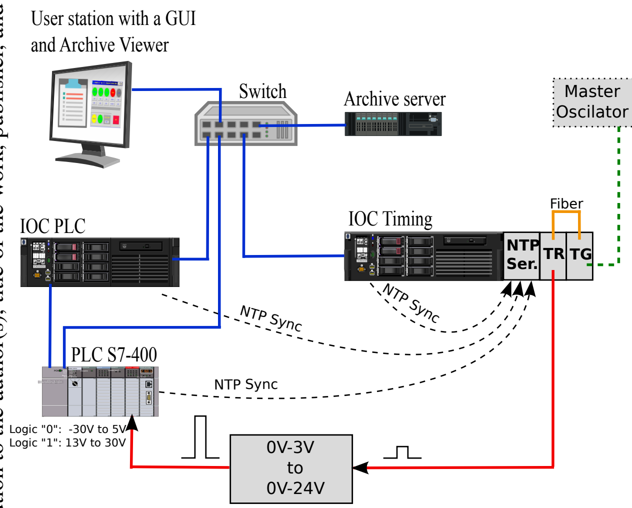

Figure 1: Timing correlation prototype.

The prototype consisted of two IOCs. One of them (IOC Timing) hosts the ICS standard timing infrastructure and the NTP server. In this IOC the ICS Timing System was set as the time provider for the NTP server and it is the time reference for all the components in the system. The EPICS program will generate a pulse on the output of the timing card and at the same time will send the timestamp of this event to the archive. The timing receiver generates an event, whose signal is acquired by the PLC (a voltage conversion is required for the signal coming out of the timing system in order to be acquired by the PLC).The voltage level translator is needed because the PLC input module and the timing card TG have different voltage levels. The output of the timing card use TTL voltage levels (logic '0' is 0V, logic '1' is 3V), while the input module on the PLC use a 24V level logic (logic '0' is -30V to 5V, logic '1' is 5V to 30V).

The IOC PLC exchanged data with a fixed refresh rate with the PLC and sent time-stamped events from the PLC to the achiever. The time on the IOC PLC was synchronised with the NTP server. An Archiving Server collected all the relevant information to be analysed from the different sources. The PLC checked every logic cycle the status of inputs and will send an event to the IOC PLC when a rising edge is detected on the input that is connected to the Timing card inside the IOC Timing . This event is acquired as an EPICS Record in both IOCs and both values will be archived later on. The goal of the activity is to measure the timestamp difference between the same event but recorded by the two different IOCs. The aim is to show that this model provides acceptable event time differences between the two sources and that event coming from PLCs can be correlated to data coming from other controllers in the machine. The testing procedure was the following

- Timing IOC must generate a pulse (30ms) on the TG card and at the same time must send a timestamp of this event to the archive.
- The PLC will detect the pulse and will send a timestamp of this event to the IOC. The IOC will add an addition time-stamp to the data from the PLC and will send everything to the archive.
- Wait for a random time (<0.5s) and then repeat the two previous steps.
- Check the correlation of events in the archive.

The result of this experiment is shown in Figure 2. Even though further measurements were made, this figure shows that depending on the configuration used, the correlation of data from PLCs to others recorded by the Timing System ranges between 0 and 100 msecs. This difference seems acceptable for the majority of the applications. However, from this experiment it was also concluded that different measures can be taken in order to control this difference for specific cases. One proposal would be to separate in one specific connection between the PLC and the IOC PLC with a limited subset of the date in order to get a faster response.

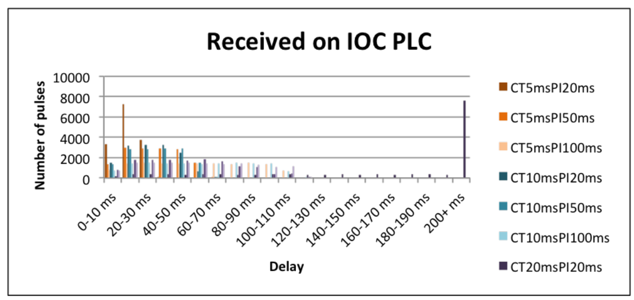

Figure 2: Number of pulses received in the IOC with a certain delay.

CONCLUSION

PLC technology will be extensively used in the ESS project. PLCs have been included in the overall hardware strategy in the Integrated Control System Division. In order to accomplish the standardisation process a comprehensive approach has been adopted. The first steps where the collection of the expected use cases and estimate the expected usage of this technology. On top of defining a PLC vendor other aspects has been considered, as the harmonisation of the technology, documentation generation and even prototyping activities. An example of one of these activities has been shown: the timing correlation prototype. From this prototype, the standard way of synchronising PLCs at ESS has been derived. The results of the experiment have been presented.

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