High performance controls architecture for real-time non-Boolean interlocks using PLCs for ESS Target system

M Zaera-Sanz, A Nordt and S Kövecses
European Spallation Source ERIC, Lund, Sweden

Manuel.Zaera-Sanz@esss.se Annika.Nordt@esss.se Szandra.Kovecses@esss.se

Abstract. The 600m long linear accelerator of the European Spallation Source ERIC, transporting a 5MWatt proton beam from the source to the target station, is currently under construction in Lund (Sweden) and plans to start neutron production in 2020. In order to protect the equipment from damage and to take the appropriate actions required to minimise recovery time, a dedicated set of Programmable Logic Controller (PLC) based interlock systems is being designed. The target protection system represents one part of the machine protection in the overall ESS protection architecture. Its main purpose is to provide dependable and, if possible, predictive interlocking for the target station and the associated subsystems (i.e. monolith, wheel, moderator-reflector system, beam extraction systems and cooling systems) in case of malfunctioning, by taking the appropriate actions to bring the machine into a safe state. This goal implies non-Boolean complex computations in real-time with critical constraints. To achieve this goal, an initial framework based on the last generation of PLCs and networking components (cluster solution) is presented. This framework is based on Siemens Totally Integrated Automation (TIA) portal with Step 7 programming environment, PROFINET fieldbus networking and intelligent devices (I-devices).

1. Introduction and requirements

Machine protection at ESS focuses on the protection of the investment (i.e. hardware) and beam (i.e. performance), hence aiming for very high beam availability towards users.

The target protection system, as part of the ESS machine protection, should fulfill a set of protection functions that are currently being defined for each subsystem: monolith, wheel, moderator-reflector system, beam extraction and cooling systems. Besides, high availability figures (95%) must be fulfilled to provide neutrons to the users.

In order to fulfill such availability figures, investment protection must be provided, and a new technique called predictive interlocking [1] is under development. Its main goal is to avoid stopping the machine by being predictive and taking the proper actions (instead of just being reactive), minimizing machine downtime and therefore saving cost in terms of equipment and labor.

Predictive interlocking will make use of artificial intelligence software techniques which may require high performance computation platforms. There are basically two problems to solve: one related to the complexity of the predictive interlocking technique to be applied, and the second one is the complexity of the set of protection functions. Implementing such complexity would require a robust platform, with real-time processing and communications constraints, and possibly SIL (Safety Integrity Level) rated. We believe that nowadays PLCs can fulfill these requirements.

The Target Protection System has to fulfil the following main requirements:
• Protect the components: In case of failure (coming from the wheel, moderator-reflector, beam extraction or cooling system), the necessary steps have to be taken leading the system to a safe state.

• Protect the beam: the system should not generate beam stops if this is not strictly necessary. Faulty trigger signals leading to neutron production stops must be kept to a strict minimum. Predictive interlocking plays a key role to provide this requirement.

• Provide the evidence: In case of failure, the operators should be given means of easy fault tracking and understanding. The system must support the identification of the initial failure, also in case of multiple alarms (one initial failure that causes subsequent failures).

• Assist improving the operation: The diagnostics for failures should be easy. The status of the system must be clearly presented in the control room and should be transparent to the operator.

To fulfil the above set of requirements we are implementing an interlock system based on three high performance PLC CPUs making use of PROFINET intelligent devices (I-devices) and shared I-devices under Siemens TIA portal [2].

2. Predictive Interlocks for ESS Target local protection system

The mission statement is to minimize machine downtime by predicting failures in the equipment and taking the appropriate action, increasing the availability and saving costs. For this purpose, PLC technology provides the needed robustness, safety and real-time performance, executing artificial intelligence software in a cluster configuration.

It is important to stress that predictive interlocks are not substituting the traditional interlocks. It is a technique applied in an above layer which purpose it is to prevent triggering the interlocks action as much as possible.

Figure 1 shows the ESS target system and Figure 2 shows an example of predictive interlocking applied to the rotating target wheel. Artificial intelligence software is monitoring the temperature of the wheel. This software is also receiving data coming from cooling, alignment and timing systems. When it detects that the wheel temperature is rising, a probability of failure associated to the cooling, alignment and timing systems is being computed. According to that probability, the health status of the related system is being evaluated; valve positions, motor speeds or timing drifts are being adjusted and the outcome is being observed. If there is no feasible solution, either no action is taken and the traditional interlocks keep operating normally, or in case the traditional interlocks are part of the predictive interlocks, the beam is being stopped.

![Figure 1. ESS target system](image-url)
3. High performance computing using PLCs: concept and implementation prototype

Our intention is to build a computer cluster using PLCs as a platform for predictive interlocking instead of using traditional computers or industrial computers.

As Figure 3 shows, any cluster solution consists of a parallel programming environment and a cluster middleware which provides a single system image. With PLCs, the parallel programming environment can be built by using STEP 7 and TIA portal tools like PROFINET I-devices and shared I-devices. The application middleware is difficult to develop, but initially we plan to implement it using a specific problem oriented approach (communicating, distributing and synchronising tasks for each specific algorithm), and in the future we plan to build a library implementing this as a single PLC system image.

We have currently built a prototype of our cluster solution based on PLCs. Figure 4 shows the main components: three PLC CPUs S7-1518, SCALANCE IRT switch, one CPU S71516, several analog and digital I/O modules in ET200MP format and SITOP redundant powering system. This cluster solution is classified as a scalable multiprocessor with physically distributed memory but logically shared. It follows a programming model based on shared memory in I-devices. Each processor acts as I/O controller and shared I-device being able to address all the memory areas. The processing information comes from an additional PLC configured also as shared I-device. We have built bus and star network topologies in order to connect our PLCs using a SCALANCE switch under real-time PROFINET profile for communications.
4. Conclusions and further work

Particle accelerators and accelerator driven facilities are time and cost critical, and predictive interlocks could play a key role:

- Avoid to stop the machine providing high availability
- Minimize machine downtime and therefore saving cost
- Speed-up machine tuning and provide advanced fault detection and fault recovery
- Perform preventive maintenance (structural health)

As further work we plan to:

- Define communications and synchronization primitives for distributed processing
- Parallelize protection functions implementation to run in the PLC cluster
- Evaluate the response time for the interlocks reaction
- In case of failsafe requirements, failsafe I-devices are possible but not “shared devices” which implies a different approach for cluster construction.

High performance computing platforms using PLCs are promising candidates for complex interlocks applications in which non-Boolean protection functions are required. Real-time high performance computing platforms to run artificial intelligence predictive interlocks software for machine protection is perhaps a good way to increase dependability.

References

[1] Zaera-Sanz M December 2014 Predictive interlocks and high performance computing using PLCs 2nd PLC based interlock systems workshop ITER International Fusion Organisation https://indico03.esss.lu.se/indico/event/218/overview

[2] Zaera-Sanz M and Nordt A February 2016 High performance computing platform for predictive interlocks using PLCs at ESS 3rd PLC based interlock systems workshop CERN European Laboratory for Particle Physics https://indico.cern.ch/event/461080/