

METHODOLOGY, DESIGN AND PHYSICAL DEPLOYMENT OF HIGHLY DEPENDABLE PLC BASED INTERLOCK SYSTEMS FOR ESS

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Abstract

Approximately 350 resistive magnets, 110 vacuum sector gate valves and 30 interceptive devices will be installed in the 600 m long linear accelerator at ESS, transporting the proton beam from the source to the target station. In order to protect this equipment from damage and to take the appropriate actions required to minimise recovery time, a dedicated set of PLC (Programmable Logic Controller) based interlock systems are being designed. The magnet powering interlock system will safely switch off a PC (Power Converter) upon the detection of an internal magnet or PC failure. The interceptive devices interlock system will protect Faraday cups, beam stoppers, wire scanners and EMUs (Emittance Measurement Units like Allison scanners and slit and grid instruments) from a beam mode that they cannot withstand by allowing/removing permission for movement or stopping beam if needed. The local protection system for vacuum will protect the vacuum sector gate valves in case of unexpected closing while running with beam. These interlock systems will inform the beam interlock system to inhibit further beam operation by requesting a beam stop if required. The methodology, design and physical deployment of the three interlock systems is presented.

INTRODUCTION

The scope of the magnet powering interlock system called LPSMAG (Local Protection System for Magnets) is to protect the magnets from damage in case of a failure in the cooling or powering systems (detected by thermo switches, flow switches and health status of the power converter), and to take the appropriate action(s) (switching of power converter and stopping beam by notifying the beam interlock system) to minimize time for recovery.

The scope of the interceptive devices interlock system called LPSID (Local Protection System for Interceptive Devices) is to protect beam (i.e. availability) and the interceptive devices from damage (allowing their insertion, extraction or movement) depending on beam mode (pulse length, repetition rate and beam current combination) and beam destination (faraday cups, beam stoppers, target or beam dump) combinations. Under some scenarios beam must be stopped by notifying the beam interlock system.

The scope of the vacuum sector gate valves interlocks called LPSVAC (Local Protection System for Vacuum) is to protect beam and the gate valves from damage (evaluating their position in or out of the beam pipe and

vacuum status) depending on the beam destination, and stopping beam by notifying the beam interlock system.

All these interlocks systems provide as output a local beam permit signal to the BIS (Beam Interlock System) requesting a beam stop if required.

Figure 1 illustrates the systems involved and their dependencies upon each other.

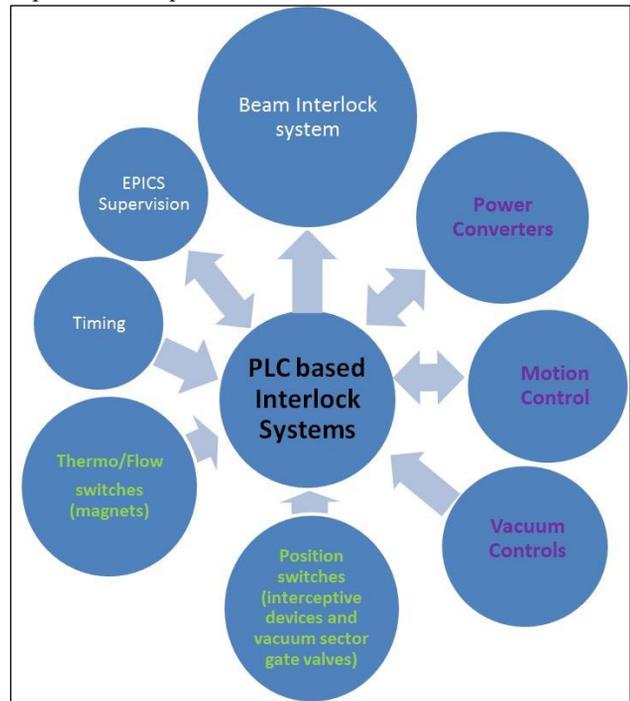


Figure 1: Relationship between PLC based interlock systems and other systems involved in protection functions.

METHODOLOGY

A formal approach based on use cases definition and discussions with the control systems experts have been followed in order to derive requirements, interfaces and behavioural models.

As outcome of this approach, general requirements, several protection functions, protection integrity levels and response times were identified for our protection systems for magnets, vacuum and interceptive devices requiring slow protection (milliseconds reaction time) where PLC technology plays a key role. The implementation of these interlock systems have to strictly comply with all identified requirements [1]. The set of signals and interfaces identified for each PLC based interlock system are shown in Figure 2, Figure 3 and Figure 4.

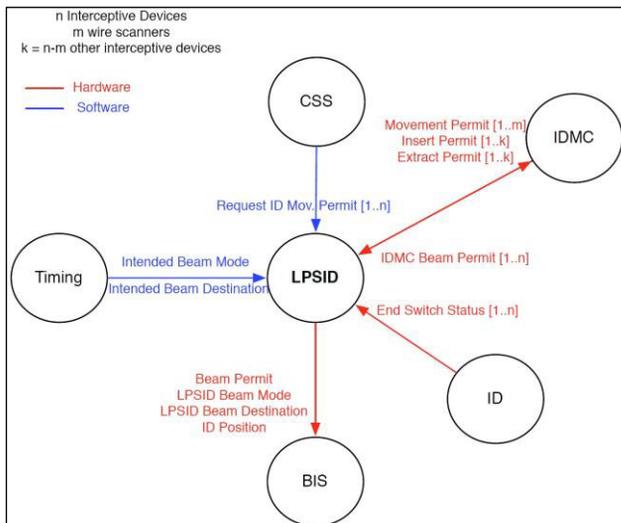


Figure 2: Interfaces between the LPSID, CSS (Control System Sequencer), IDMC (Interceptive Devices Motion Controller), BIS, Timing and IDs (Interceptive Devices).

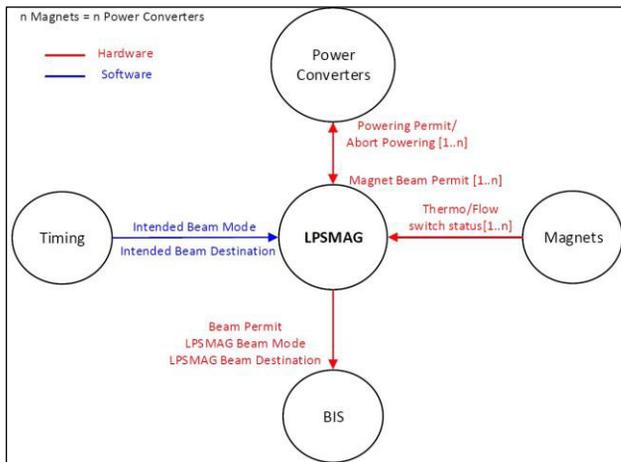


Figure 3: Interfaces between the LPSMAG, Power Converters, Magnets, BIS and Timing.

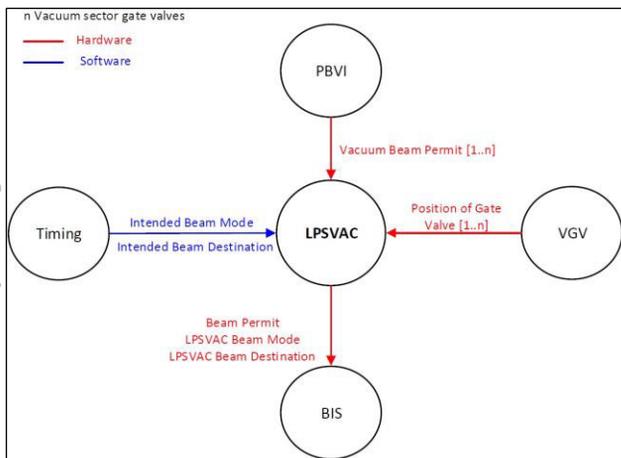


Figure 4: Interfaces between the LPSVAC, PBVI (Proton Beam Vacuum Interlock), VGV (Vacuum sector Gate Valves), BIS, and Timing.

DESIGN

As depicted in the methodology a set of hardware and software signals have to be exchanged between several systems.

The exchange of hardware signals is performed using failsafe logic [2]. Nominal operation of the system is represented by an active signal. An active signal corresponds to a flowing current in the loop, while a deactivated signal or a loss of the supply results in a safe state of the system.

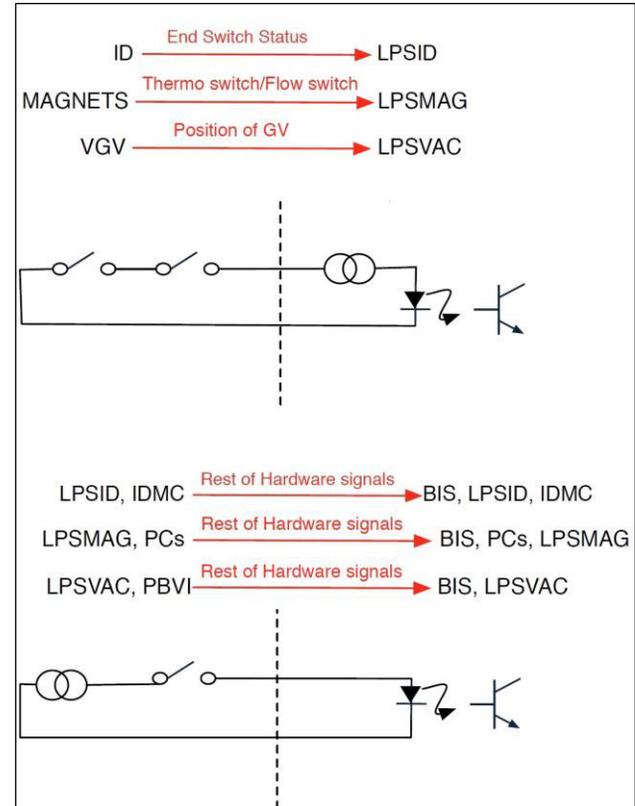


Figure 5: Hardware signals exchange between each local protection system and the rest of the systems involved.

As Figure 5 depicts, the positions of the interceptive devices, thermo switches/flow switches or vacuum sector gate valves are detected by using dry contacts (two in series or one non-equivalent switch). The positions are read by the local protection systems by an optocoupler.

The rest of hardware signals are exchanged similarly by generating a current loop and opening/closing the related switch at the local protection system side. The other related systems read the signals by using an optocoupler.

The exchange of software signals is performed by using EPICS (Experimental Physics and Industrial Control System). The PLCs run an EPICS driver able to communicate with an EPICS IOC (Input Output Controller) where all the PVs (Process Values) related to machine protection local protection systems are managed. A subscription to the proper variables for each local protection system allows reading out the state of each software signal.

PHYSICAL DEPLOYMENT

Figure 6 shows the physical deployment of the three systems that machine protection is currently developing.

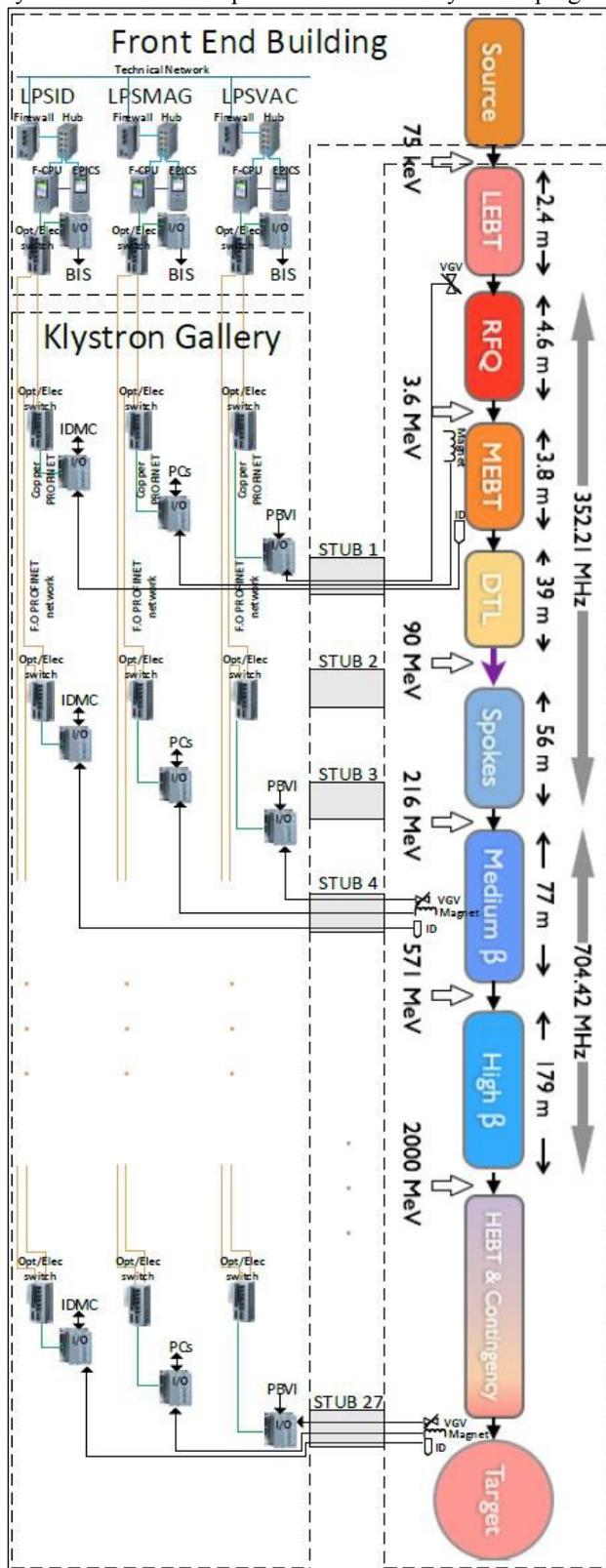


Figure 6: Physical deployment of the PLC based local protection systems and their interconnections.

The three accelerator related local protection systems are physically distributed along the front end building and klystron gallery interconnecting all the protected elements (interceptive devices, magnets and valves), and interfacing with additional subsystems (motion controllers, power converters and vacuum controls).

The CPUs of the PLCs will be located in the front-end building and networked protected by firewalls. Two CPUs per interlock system are foreseen. One for failsafe operation (F-CPU) and the other for EPICS communications.

In order to read information from sensors like position switches of valves and interceptive devices or temperature/flow switches for magnets, a set of PLC I/O modules will be installed. These I/O modules are distributed mainly along the klystron gallery. For high availability purposes, they are interconnected by fiber optics networks in a ring topology (one ring per local protection system), and PROFINET copper cable locally inside each enclosure along the klystron gallery in a bus or star topology (not yet decided). For the interconnection of these PLC I/O modules with the devices located in the accelerator tunnel (valves switches, magnets switches and interceptive devices switches), a radiation and high temperature resistant cable and connectors with keying will be installed. The same cable and connectors will be used in order to interconnect the local protection systems with other related systems like motion controllers, power converters and vacuum controls.

In order to stop beam if required, an interconnection with the BIS is foreseen in the front end building providing the local beam permit signals for each local protection system. A set of current loops in 2-out-of-3 redundancy are foreseen as interface with the BIS.

CONCLUSIONS

The implementation of the first prototypes based on the described concepts has yielded promising results, both in terms of performance as well as dependability. The prototypes have been conceived to scale to all the interceptive devices, valves and electrical circuits needed for the final ESS local protection systems operation.

Future works include the programming of the supervision interface and CPU communications, additional response time evaluations under more realistic scenarios, and the design of automatic test and diagnostic features to guarantee system integrity though operation.

REFERENCES

- [1] R. Schmidt, A. Apollonio, D. Curry, A. Nordt, "Architecture of the ESS machine protection system", ESS Engineering specification, February 2014.
- [2] R. Schmidt, P. Dahlen, B. Puccio, M. Zerlauth, "The hardware interfaces between warm magnet interlock system, normal conducting magnets, power converters and beam interlock system for the LHC ring", Engineering specification, CERN ref. No. LHC-CIW-ES-0001, September 2005.