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IMPLEMENTATION OF THE PLC BASED MACHINE PROTECTION SYSTEM FOR MAGNETS AT ESS

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Abstract

The European Spallation Source ERIC (ESS) will be the most powerful neutron source in the world, aiming at an average beam power of 5 MW. One of the ESS goals is to deliver neutrons with a 95% overall availability for the 22 research instruments that will be installed at the ESS. To reach this goal, the Protection Systems Group (PSG) develops several interlock systems. One of these systems is the Machine Protection System (MPS) for Magnets (MPSMag), which collects signals from the Local Protection Systems (LPS) of each of the 150 quadrupole magnets distributed along the 600 meters long Linear Accelerator (LINAC). When MPSMag detects a failure of any quadrupole magnet systems, it triggers a beam stop.

The MPSMag design implements requirements from the stakeholders of the LPS for quadrupoles (LPSMag), operations and accelerator teams.

The concept of operation, software design and hardware architecture will be presented in this paper.

INTRODUCTION

Machine Protection supports ESS in reaching its reliability, availability and maintainability goals, in the following way [1, 2]: protect the facility by not allowing proton beam production if a condition could lead to beam induced damage; protect the beam by generating beam interruptions only if strictly necessary; support identifying the initial failure.

Protection functions that span across several systems, are called global protection functions. Protection functions that are part of only one system, are called local protection functions. The time response requirements for executing a protection function, can be very different, ranging from a few microseconds (fast response time) to several hundreds of milliseconds (slow response time). The Beam Interlock System (BIS) implements the logic for global protection functions and consists of several PLC based Machine Protection Systems (MPSs) to implement slow global protection functions and the Fast Beam Interlock System (FBIS) to execute fast global protection functions. The FBIS is the link between the MPSs and the actuator systems and only the FBIS triggers a beam stop. The FBIS has a time response of microseconds. The relation between Local Protection Systems, the Beam Interlock System and the Actuator systems is shown in Figure 1.

The first MPSMag prototype has been implemented using Siemens industrial Programmable Logic Controllers (PLCs), the PROFINET real-time fieldbus communications protocol and Siemens Totally Integrated Automation (TIA) Portal software.

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CONCEPT OF OPERATION

The concept of operation for the MPS [3] is inspired by the ISO 15289 standard. MPSMag has interfaces with different systems to fulfil the protection functions and a description of the signals exchange and interfaces is given in Figure 2.

MPSMag exchanges software signals such as Proton Beam Mode, Proton Beam Destination, configuration and all the Process Values (PV) related to machine protection with Experimental Physics and Industrial Control System (EPICS) through an Input Output Controller (IOC).

The Timing system has a Network Time Protocol (NTP) for MPSMag PLC events time stamping.

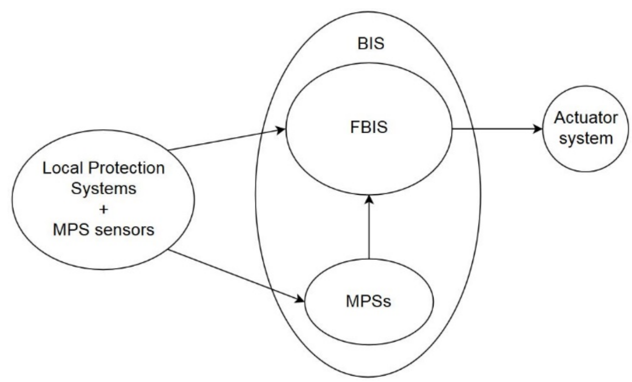

Figure 1: Relation between local Protection Systems, the Beam Interlock System and the actuator systems. The Beam Interlock System consists of PLC based Machine Protection Systems (MPSs) and the Fast Beam Interlock System (FBIS).

The Local Protection Systems for the quadrupole magnets (LPSMag's) protect the magnets from overheating or faults in the powering system. The LPSMag's send Local Beam Permit signals, OK or NOT OK (NOK) to MPSMag. The LPSMag in the Normal Conducting Linac (NC-Linac) is a Programmable Logic Controller (PLC) which sends one Local Beam Permit signal for each quadrupole in the Medium Energy Beam Transfer line (MEBT) to MPSMag. In the Super Conducting Linac (SC-Linac), the LPSMag is implemented on the level of the power converters. Each power converter sends a Local Beam Permit signal for each quadrupole to MPSMag.

In case a Local Beam Permit signal of a quadrupole upstream of the Proton Beam Destination is NOK, the MPSMag initiates a beam stop or prevents beam operation sending a Magnet Beam Permit (MBP) signal NOK to the FBIS. In addition, MPSMag sends the configured Proton Beam Mode and Proton Beam Destination, Keep alive signal, and

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redundant MPSMag Ready and MPSMag Beam Permit to FBIS via PROFINET.

MPSMag provides a masking functionality, allowing for operation also in case certain devices are not functional (or not yet installed as it will be the case during the early commissioning of the LINAC).

In case of a failure of a non-critical component, such as the NTP server, EPICS communication, one of the redundant power supplies or the Human Machine Interface (HMI) panel, the MPSMag shall still operate. The MPSMag Beam Permit and MPSMag ready signals shall be still to OK and the system shall be able to re-arm in case of interlock. After a maintenance operation of the system, MPSMag shall be fully operational, that means the EPICS communication, both power supplies, HMI and the I/O modules shall be OK again. MPSMag archives input and output changes and relevant internal information in a buffer together with a timestamp that can be read by EPICS for diagnostic purposes at any time.

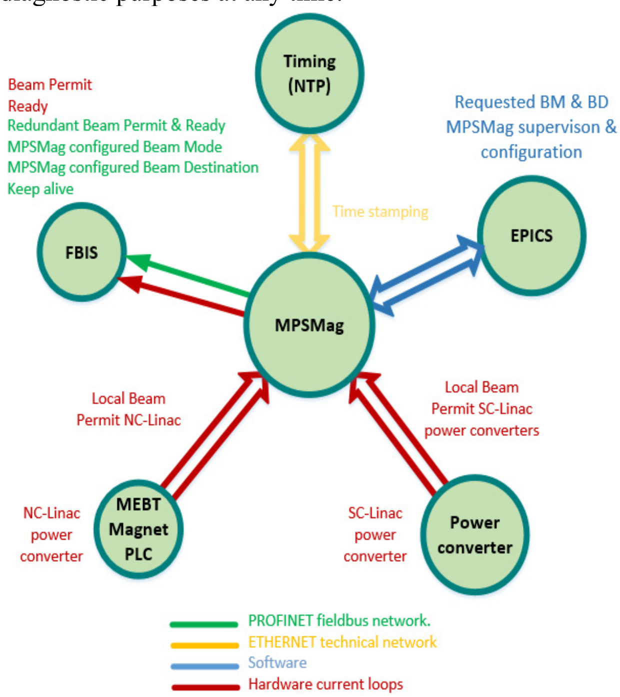

Figure 2: MPSMag signals exchange.

After a power-on MPSMag checks its own health, and if it is OK, it calculates checksums of its hardware and software. These values are sent to EPICS to do a consistency check.

SOFTWARE DESIGN

The software design for the PLC based interlock systems used for Machine Protection [4] is modular and allows scaling the systems with every ESS construction phase without having to verify previously validated section of code again. All the interlock systems share common functions and data types, which are stored in a global library. The MPSMag specific functions and data types are stored in the project library. This method reduces code development and testing time because the code and data types need to be qualified only once. Moreover, the change control management is more efficient and reduces the human errors when developing code.

MPSMag software is implemented in two PLCs, one failsafe PLC for the logic of global protection functions, and a standard PLC to pass information to EPICS and the HMI [4].

The software design is based on the state machine methodology, using state equations and output equations. Figure 3 shows the state machine for MPSMag.

The MPSMag inputs are all hardwired LPSMag signals and the system configuration (via EPICS). MPSMag outputs are hardwired signals (MPSMag Beam Permit and MPSMag Ready). The MPSMag outputs are sent to the Fast Beam Interlock System (FBIS) via current loops and via PROFINET.

In the start-up state, The PLC performs the start-up configuration process. This process consists of reading the PLC stored checksum value from EPICS and comparing with the calculated checksum. This is needed to ensure the correct version of code is in the PLC.

In the attempting arm state, the PLC checks if the required Local Beam Permits for the quadrupoles upstream of the configured Proton Beam Destination are OK.

In the armed state, the PLC is ready for beam operation and all the considered protection functions are ready for execution. MPSMag Beam Permit and MPSMag Ready signals are set to OK.

In the interlocks state, no beam is allowed and the PLC is not ready due to the passivation generated by the interlocks (i.e. MPSMag Beam Permit NOK, MPSMag Ready NOK). The PLC system remains in this state until a manual rearming (through EPICS) is done.

In the machine reconfiguration state, MPSMag Ready is NOK as the machine is being reconfigured but no re-arming is required by the operator as it is not an interlock situation. As soon as all the conditions for beam operation are met again, the PLC system goes into the armed state.

Internal logging of events takes place periodically (each PLC scan cycle) and the data is sent to EPICS for monitoring and further stored in a database. The PLC updates an internal memory circular buffer to store all the variables of the system in case of interlock. In case the communication with EPICS is lost when an interlock occurs, this valuable information will be available when the communication with EPICS has recovered.

Additionally, in every state the checksum of the failsafe PLC and standard PLC codes are compared to the stored value. If any potential difference is detected the PLC system will go to start-up state.

TIA Selection Tool was used to evaluate the time response of the design and verify the requirements.

HARDWARE ARCHITECTURE

MPS electrical design is based on rack systems. The installation of the racks follows the ESS construction phases. To scale the system the crates design inside the racks is modular, reducing the testing and validation time and improve the flexibility of the system. Only two different kind

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of crates have been designed for all the PLC based interlocks systems: Remote I/Os and Power Supply Units (PSU).

The MPSMag hardware architecture is based on the Siemens S7-1500 series, with one failsafe PLC (1516F-3PN/DP), called MPSMag-FCPU that can provide up to SIL 3 and time response of hundreds of milliseconds and one standard PLC (1516-3PN/DP), called MPSMag-GCPU (Gateway CPU), to exchange data with the SCADA system an EPICS.

Remote I/O crates are distributed along the klystron gallery to read the Local Beam Permit signals. The remote I/Os are based on the Siemens ET-200SP series. The fieldbus network inside the crates is PROFINET with PROFISAFE profile in copper with star topology. The connection between the crates is done with optical/electrical switches (SCALANCE XC206-2 SFP) in a bus topology.

To increase the reliability of MPSMag, failsafe logic is used to perform the exchange of hardware signals. 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 loss of the supply results in a safe state of the MPSMag. The implementation of the interface between MPSMag and the Local Protection Systems is shown in Figure 4.

The hardware connections for MPSMag Beam Permit and MPSMag Ready signals are current loops in 2-out-of-3 redundancy.

Inside the PSU crates a redundant power supplies system has been implemented with the SIEMENS SITOP solution; allowing module switchover if one power supply fails. When both power supplies fail, an interlock is triggered. To allow a remote reset of the interlock systems a Siemens LOGO solution is used to restart the power on demand.

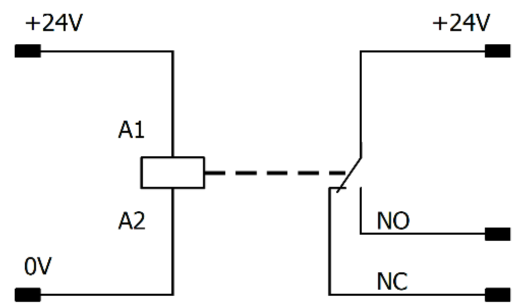

Figure 4: Interface between MPSMag and LPSMag in the Normal Conducting-Linac and the Super Conducting-Linac (SCL).

CONCLUSION

The implementation of MPSMag is based on the concept of operation and system architecture providing fast scalability and reducing verification and installation times. The system has been tested and relevant dependability requirements have been achieved. The supervision interface, PLCs communications and the HMI panel have been programmed and tested.

In the next few months, commissioning of MPSMag will start.

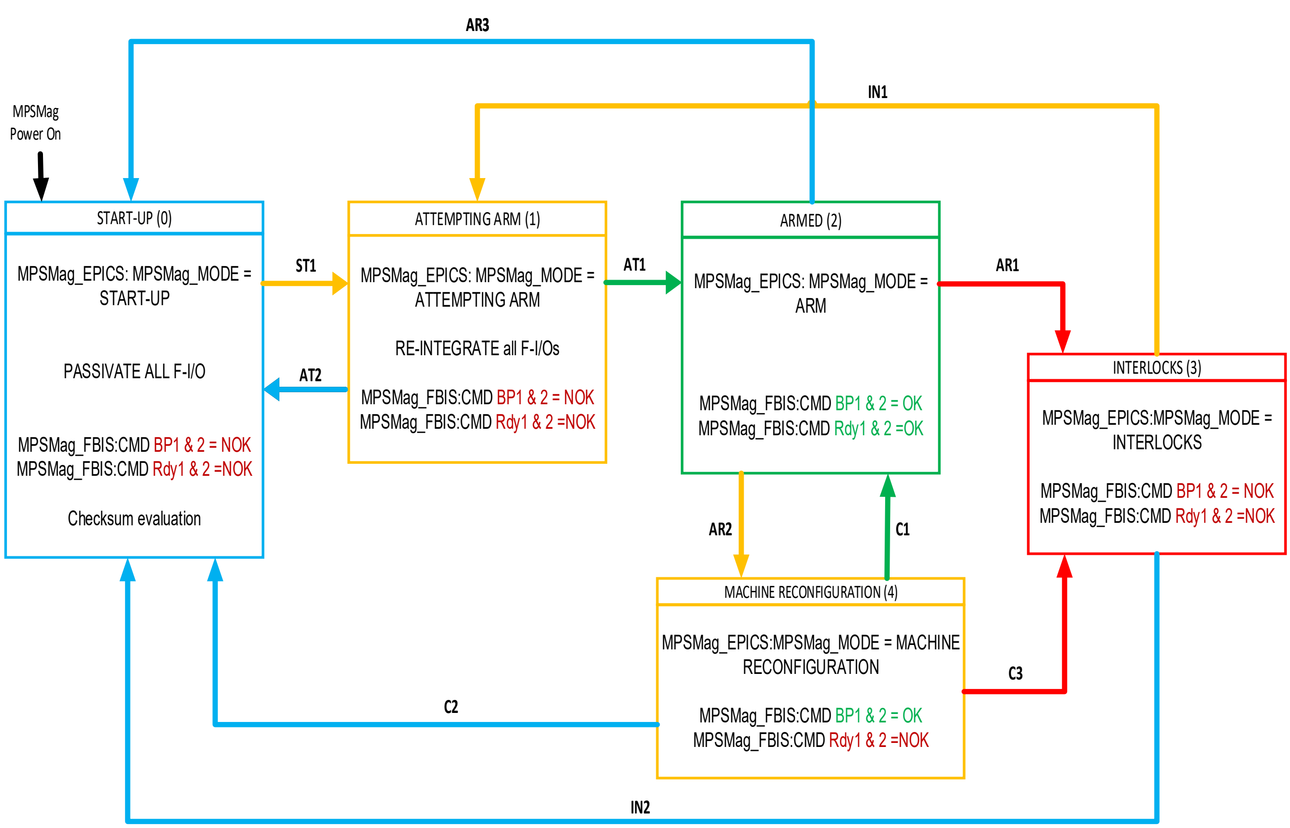

Figure 3: State machine for the ESS Machine Protection System for Magnets.

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REFERENCES

[1] R. Garoby *et al.*, "The European Spallation Source Design", *Physica Scripta*, vol. 93, no. 1, p. 014001, Jan. 2018. doi:10.1088/1402-4896/aa9bff

[2] A. Nordt, A. Apollonio, and R. Schmidt, "Overview on the Design of the Machine Protection System for ESS", in *Proc. IPAC'14*, Dresden, Germany, Jun. 2014, pp. 472-475. doi:10.18429/JACoW-IPAC2014-MOPME045

[3] David Sánchez-Valdepeñas, "Machine Protection System for Magnets (MPSMag) Concept of Operation", ESS-0402663, Lund, Sweden, May 2019

[4] Manuel Zaera Sanz, "System Architecture of PLC based Machine Protection Systems", ESS-0239641, Oct. 2018