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TARGET CONTROL AND PROTECTION SYSTEMS LESSONS FROM SNS OPERATIONS*

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Abstract

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory has been in operations since 2006 and proposes a project to build a Second Target Station (STS) to effectively double potential scientific output. The SNS target controls operate in a harsh environment which includes high radiation, exposure to gaseous radionuclides, and activated liquid mercury and mercury vapor. These conditions necessitate protective interlocks and credited controls for protection functions to ensure proper response to off-normal conditions. In order to inform the design of target controls for the STS, we have examined lessons learned during SNS operations regarding the design and implementation of the control and protection systems for the first target station (FTS). This paper will examine various aspects of the performance of the target control and protection systems including reliability, maintainability and sustainability given the challenging environment created by 1.4 MW operations. Specific topics include distributed control of various target subsystems, response to loss of power, selection of nuclear grade instrumentation, and applying these lessons to the design for the STS project.

INTRODUCTION

The Spallation Neutron Source (SNS) [1] is an accelerator based neutron source at the Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. The SNS is a U.S. Department of Energy user facility that hosted over 1300 users in 2018. It provides the world's most intense, pulsed neutron source for scientific research. The SNS machine consists of a 1.4 MW accelerator that delivers pulsed protons to a liquid mercury target which in turn spalls neutrons. The neutrons are moderated and guided through 16 instrument beamlines to a variety of sample environments for research in a broad range of scientific disciplines.

The existing complex was designed with provisions for a Second Target Station (STS) which would provide space for up to 22 additional instruments. The STS would share beam pulses from the existing SNS accelerator. The STS will provide intense cold neutrons with a longer wavelength which will significantly enhance neutron brightness as compared to the first target station (FTS). ORNL is currently working on the STS conceptual design. [2]

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The STS target design calls for a segmented rotating assembly (Fig. 1) consisting of tantalum-clad tungsten blocks. The target rotation will be controlled so that it is synchronized to the proton beam using the existing accelerator timing system, which will be extended to the new target station.

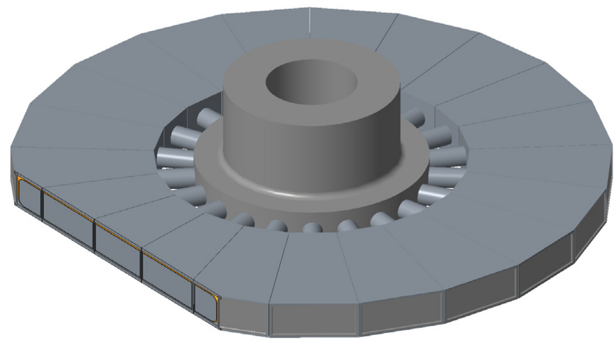

Figure 1: STS Target assembly disk conceptual design, with cutaway to show tantalum cladding on tungsten blocks.

In order to inform the design for STS target controls, we have examined lessons learned from operating and maintaining the FTS for over a decade. Relevant topics include distribution of processors for target subsystems, response to loss of PLC power, selection and maintenance of instrumentation, and credited controls and protective functions Lessons Learned from FTS

Integrated Control System Structure for Target Subsystems

The existing SNS Integrated Control System (ICS) uses the Experimental Physics and Industrial Control System (EPICS) toolkit as an integrating framework for a large set of diverse devices used to monitor and control the accelerator complex, target, and instrument suite. The scope for STS target controls includes control system hardware, software, interlocks and user interfaces integrated with the SNS ICS. The target controls design for STS will follow the FTS model of using commercial industrial PLCs with appropriate instrumentation to provide STS target control. The process instrumentation and control for the target systems will be designed to connect to the existing machine control system, in a similar manner as FTS, to provide both safety-related and non-safety-related control, equipment protection, and monitoring for the target systems. The target instrumentation will interface to the machine network so that the target systems can be controlled from either the Central Control Room or the STS Target Control Room. Target startup and control system maintenance will be performed from the STS Target Control Room.

The existing FTS target controls architecture uses IOC/PLC pairs shared across multiple target subsystems.

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This has proven problematic in terms of broadening the impact of a failure or even maintenance work. Target controls for the STS will incorporate a more distributive control architecture for various STS subsystems as compared to the FTS. This will be accomplished by implementing dedicated Input Output Controller (IOC) and Programmable Logic Control (PLC) pairs using an ethernet network for each target subsystem (Fig. 2). Providing dedicated processor pairs will minimize the impact of taking a given subsystem offline for maintenance and therefore reduce the time necessary to restore the machine for operations following such work. This arrangement will increase reliability by mitigating the impact of a single processor failure to only the related subsystem instead of affecting multiple subsystems thereby reducing the time necessary to recover from a failure. It also ensures faster controller processing times since it the processor is local to the field, decreasing network processing delays.

Various STS subsystems will provide interlocks to the existing Machine Protection System (MPS), similar to the FTS arrangement. The STS control system PLCs will include MPS set points on multiple process parameters that output parallel trips to the two existing MPS paths: the fast trip system that uses Field Programmable Gate Arrays (FPGAs) and the PLC based system. The MPS parameters in the target controls will include redundant and diverse parameters to trip the proton beam when necessary to prevent damage to the target due to predefined off-normal conditions.

Response to Loss of PLC Power

The existing FTS PLC cabinets were not originally designed to include an Automatic Transfer Switch (ATS), but there is currently a campaign to retrofit the cabinets to include them. An ATS will be installed in each PLC cabinet in the STS to provide reliable, redundant 120VAC power. This will mitigate the vulnerability of power loss and further ensure the reliability of the target subsystems. The PLC cabinets will be normally supplied by UPS power but under a power failure or when power is out of the selected range, the ATS will supply a secondary line power to the cabinet. The transfer will be seamless without interrupting critical loads.

Another issue with power reliability at the FTS is failure of 24V power supplies. A preventative maintenance (PM) schedule will be implemented for the STS to replace the power supplies at a scheduled interval to prevent failure during service.

Selection and Maintenance of Instrumentation

The instrumentation used to support target processes are often located in a harsh environment containing high radiation, exposure to gaseous radionuclides, activated liquid mercury, and mercury vapor. Although the specification and design of the instrumentation for STS will be equivalent to the FTS equipment, there are some cases where improvements will be made.

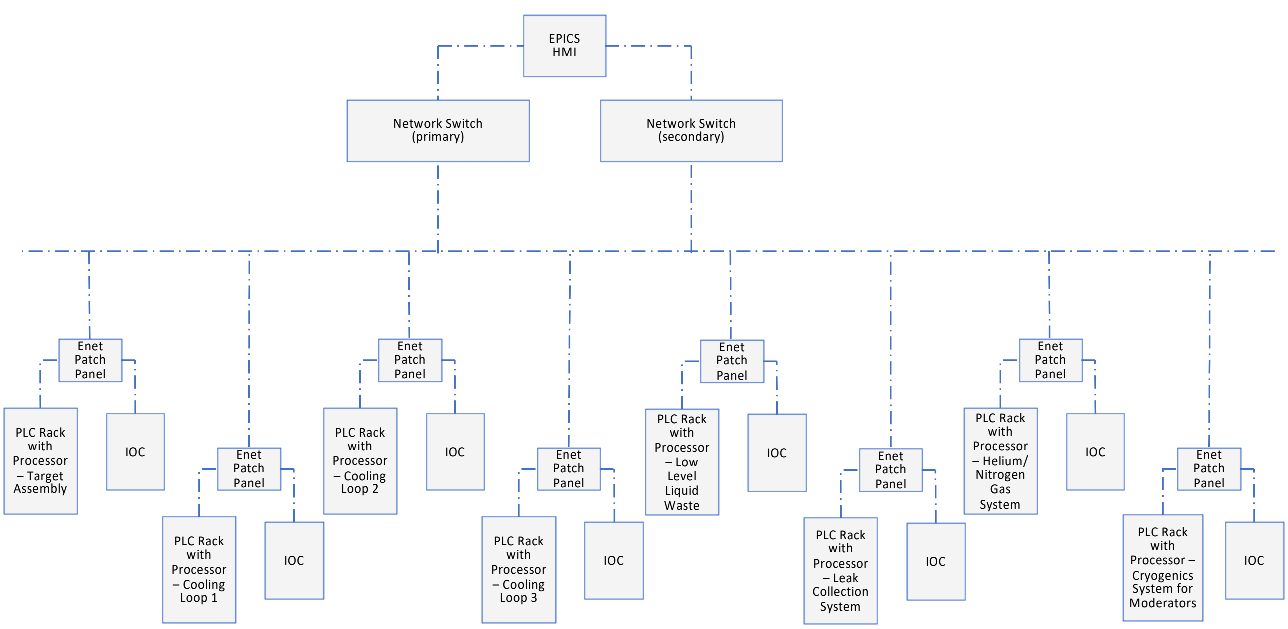

Figure 2: Distributed Control of Target Subsystem for STS.

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Some of the original FTS instrumentation, located in a harsh environment, was custom made to withstand the environmental conditions to save the cost of purchasing nuclear qualified equipment. This has caused problems because as the sensors reach the end of their service life, replacements cannot be purchased because some of the vendors will no longer fabricate the custom sensors. An effort has been made to have other manufacturers reverse engineer the sensors but this approach requires many engineering hours, often with long manufacturing lead-times, and inflated costs. Some of the original sensors have been replaced with commercial grade equipment to avoid the cost of retrofitting the design with nuclear grade instrumentation. The commercial grade instruments degrade and fail prematurely in the harsh environment causing the instrumentation to be unreliable. Special care will be taken to ensure the instrumentation for STS is properly specified to withstand the environmental conditions without affecting accuracy and reliability of the device. In addition, each device type will have standardized manufacturer and models to better manage spares and improve maintainability. Custom manufactured instruments will be avoided and models that are supported for the nuclear industry will be chosen. This will minimize obsolescence issue and maximize service life since most of the nuclear qualified instrument have a high allowable total ionizing dose (TID).

A calibration program for instruments that are critical to beam production does not currently exist for FTS partially because some of the instrumentation is inaccessible for calibration. A calibration program for this instrumentation will be implemented for the STS and accessibility of the instrumentation will be designed such that regular maintenance and calibration can be performed.

FTS does not have redundant sensors for instruments that are critical to beam production and therefore is at risk for a single point failure. These instruments for STS will have redundant sensors using 2 out of 3 voting logic so that if a sensor fails, production time is not lost.

Credited Controls and Protection Function for the Target Protection System

Credited Engineering Controls (CECs) and protective interlocks are required to support off-normal conditions for the STS. CECs are designed to protect the public and facility workers from hazards like mercury vapor and radiation. The STS Target Protection System (TPS) [3], like that of FTS, will be a credited protection-class system that will monitor the target for abnormal conditions and shut down the proton beam if required. The TPS for the STS will not be a stand-alone system; instead, it will be integrated into the FTS TPS. The design for the STS TPS will be leveraged off of the FTS TPS since it has been thoroughly tested for safety and functionality.

The TPS parameters will be isolated inputs to the Target Control System for monitoring and will also trip the beam through the MPS. These parameter for FTS includes mercury temperature, mercury flow, and mercury pump power. The parameters for the STS TPS will be defined by the Accelerator Safety Envelope (ASE) document later in the project design phase. The conceptual design is such that improper rotation (in either speed or phase) or no rotation of the target disk will initiate an interlock to the TPS and/or MPS to terminate beam.

The STS TPS system architecture will consist of two channels with a single failure criterion. This will allow the system to be placed in a safe state if a fault occurs in one of the two channels. The channels will have proper separation to avoid common cause faults. Structures will be seismically qualified to withstand the predetermined criteria defined by the ASE.

The FTS utilizes the Radio Frequency Quadrupole (RFQ) contactor and the Ion Source contactor as critical devices to shut down the proton beam. Both of these critical devices are located at the front end of the accelerator. Since the STS design is still in the conceptual phase, it has not yet been determined if the STS portion of TPS will utilize one of these existing critical devices or create a new critical device to turn off beam to one target station while sending beam to the other. It would be advantageous to use the existing critical devices since they have already been tested and are on a PM schedule. Alternatively, adding new critical devices to shut off the beam to only one the target station would require periodic certification and maintenance, but would provide additional flexibility for beam production.

CONCLUSION

In order to inform the design for STS target controls, we have examined lessons learned from FTS operations regarding the design and implementation of the control and protection systems. We have evaluated various aspects of the performance of the target control and protection systems including reliability, maintainability and sustainability. Areas of improvement include integrated control system structure for target subsystems, response to loss of PLC power, selection and maintenance of instrumentation, and credited controls and protective functions for the target protection system.

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