ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOAPP03

CONTROL SYSTEM PLANS FOR SNS UPGRADE PROJECTS*

S. M. Hartman†, K. S. White‡
Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

Abstract

The Spallation Neutron Source at Oak Ridge National Laboratory is planning two major upgrades to the facility. The Proton Power Upgrade project, currently underway, will double the machine power from 1.4 to 2.8 MW by adding seven additional cryomodules and associated equipment. The Second Target Station project, currently in conceptual design, will construct a new target station effectively doubling the potential scientific output of the facility. This paper discusses the control system upgrades required to integrate these projects into the existing EPICS-based control systems used for the machine and neutron instrument beamlines. While much of the control system can be replicated from existing solutions, some systems require new hardware and software. Operating two target stations simultaneously will require a new run permit system to safely manage beam delivery.

SPALLATION NEUTRON SOURCE

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) is the world's most intense source of pulsed neutrons for research. The SNS consists of a 1 GeV superconducting hadron linac operating at 60 Hz, producing a 1.4 MW proton beam on target. An accumulator ring compresses the ~1 ms macropulse from the linac into a ~700 ns pulse. The pulse is extracted from the ring in a single turn and directed towards a liquid mercury target. Neutrons are spalled from the mercury nuclei, moderated to thermal or cold kinetic energies, and transported to experiment endstations where they are used for a wide-range of science research.

Completed in 2006, the original SNS construction project was managed as a collaboration of six national laboratories with each of the major subsystems the responsibility of a partner laboratory. The control systems for the SNS project were managed as the "Integrated Control System" (ICS) at the same organizational level and reporting level as the primary facility components [1]. Experimental Physics and Industrial Control System (EPICS) [2] provided a common integration layer for subsystem controls delivered by partner laboratories. In addition to the use of EPICS for accelerator controls, EPICS was also used successfully for integration of industrial and process controls including utilities for the target systems, building automation systems for technical buildings, and process control for the cryogenics systems. EPICS, however, was not used initially for the neutron scattering beam lines and instrument data acquisition. A later multi-year upgrade migrated these systems to EPICS [3] with completion in early 2019.

SNS UPGRADE PROJECTS

Two projects are currently underway to substantively upgrade the SNS and expand the capabilities of the facility. The Proton Power Upgrade (PPU) Project will increase beam power. The subsequent Second Target Station (STS) Project will utilize this increased power to support a second experiment hall, effectively doubling the capacity for neutron scattering beam lines. The existing First Target Station (FTS) will remain optimized for thermal neutrons offering spatial resolution on the atomic scale delivered in short pulses optimized for fast dynamics studies of materials. The STS will be optimized as a facility to probe structure and dynamics of materials over extended length, time, and energy scales using longer wavelength cold neutrons pulsed at a lower repetition rate.

PROTON POWER UPGRADE

The Proton Power Upgrade (PPU) will double the SNS beam capability from 1.4 MW to 2.8 MW. This will be achieved through a 30 % increase in beam energy and a 50 % increase in beam current. 2 MW of power will be delivered to the FTS. The project includes installation of 7 additional superconducting cryomodules to the existing linac with supporting radio frequency (RF) systems, modifications to the ring injection region and extraction kickers for the higher beam energy, and improvements to the target systems for the higher beam power.

Accelerator and target controls upgrades are largely extensions of existing technologies. The control system will build on and leverage the existing EPICS-based control system.

PPU Controls

The PPU Project adds 7 new cryomodules to the linac. Controls for the existing cryomodules, which consist of Allen-Bradley ControlLogix programmable logic controllers (PLC) and EPICS VMEBus Input/Output Controllers (IOC), will mostly be replicated. However, to address obsolescence, some input/output (I/O) will be migrated from VMEBus to PLCs. Existing sequencers and automation routines will be updated to support the expanded linac. Beam line vacuum and cryomodule insulating vacuum will be replicated based on current PLC plus EPICS designs.

* This manuscript has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the US Department of Energy (DOE). The US government retains and the publisher, by accepting the article for publication, acknowledges that the US government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for US government purposes. DOE will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan)
† hartmansm@ornl.gov
‡ whiteks@ornl.gov

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOAPP03

Controls for high-power RF will be replicated to support the new systems. The low-level RF (LLRF) will be a new design due to obsolescence of the original design. The LLRF will change from a VXI platform to a μTCA platform and will support pulse-by-pulse feedback.

The existing control system ethernet network, Machine Protection Systems (MPS), and timing system will be extended to support the new devices. Conventional facilities controls include support for an additional de-ionized water system and expanded building heating, ventilation and air conditioning systems.

Protection Systems

The existing PLC-based personnel protection system (PPS) will be extended to support new devices. However, the PPU presents a new PPS requirement. The accelerator safety envelop allows for a maximum power to the first target of 2 MW. After the PPU project, the accelerator will be capable of producing a 2.8 MW beam. A credited control is required to limit power below the safety envelop threshold. This will require a credited system to measure the pulse energy and trip the beam if power exceeds this threshold. The expectation is that the beam power limiting system will consists of an analog front-end and an FPGA-based digital back-end [4]. This would be the first such digital device used as a credit control at SNS.

SECOND TARGET STATION

The STS Project builds on the performance gains delivered by PPU to create a world-leading source of cold neutrons of unprecedented peak brightness. The scope includes an accelerator addition of a ring-to-second-target beam transport line operating at 15 Hz; a water-cooled, rotating, solid-tungsten target with compact moderators; eight neutron scattering instruments; conventional facilities including a target building, three instrument buildings, a central utilities building, and an addition to the existing laboratory and office building; and the integrated control systems and computing infrastructure for all technical systems included in the STS.

The Integrated Control Systems (ICS) organization builds on the experiences and lessons learned from the original SNS construction project. Like the original project, ICS will be managed at the same level as accelerator systems, target systems, instrument systems, and conventional facilities. EPICS will be used as the integrating framework for the control systems. This includes accelerator, target and conventional facilities control systems as was done with the original project. For the STS project, ICS scope will also include controls and data acquisition for the neutron scattering instruments, unlike the original project where this scope was managed as part of the instrument systems.

Modifications and additions to the Personnel Protection System (PPS) required for the accelerator, target, and STS instruments are also included in this scope. The ICS will provide supervisory control, automation, and operational tools for the upgraded facility. The control system includes hardware interfaces to technical systems, process control software, timing and communication networks, and user interfaces. Operational tools include system data archiving, alarm systems, and databases. The ICS has interfaces to technical systems across the project.

The baseline design for STS controls utilizes EPICS 7 [5] and Control System Studio [6].

Accelerator Controls

The ICS scope for the accelerator includes control system hardware, software, and user interfaces for the accelerator systems, including the EPICS-based controls system, programmable logic controller-based controls, device integration, timing system, MPS, PPS, and related computing infrastructure. Device control includes magnet power supplies, extraction kickers, vacuum systems, RF systems, cooling systems, etc.

The SNS accelerator will continue to operate at the same repetition rate as currently, 60 Hz. With the STS in operation, the accelerator will typically deliver 45 pulses per second to the FTS and 15 pulses per second at 15 Hz to the STS. The STS will be operating in a “pulse stealing” mode: three pulses will be delivered to FTS and every fourth pulse delivered to the STS.

Independent operation of beam power to the two target end-stations requires the ability to accommodate different beam power pulse-by-pulse through the accelerator chain. The ion source injector current output cannot be changed quickly, nor can the accelerating gradient which determines beam energy. Beam power will therefore be adjusted by modifying the mini-pulse of the proton beam, either by changing the number of mini-pulses within a macro-pulse and/or by adjusting the length of each mini-pulse.

To provide this level of control, the LLRF will need to be able to provide different control and feed forward for the different beams going to FTS or STS. An upgrade to the LLRF hardware is being developed as part of the PPU Project and is expected to be available to meet STS LLRF needs after some modification of the firmware and EPICS control.

The Run Permit System is the combination of timing, messaging, machine protection, and high-level applications used to configure and deliver beam to the target(s). Part of the STS Project is to create a supervisory application that coordinates all of these as well as provides the operator with a consistent user interface. This will enable smooth transitions between operation modes which can include both FTS and STS or either FTS or STS independently.

Target Controls

The ICS scope for the target systems includes control system hardware, software, and user interfaces, including the EPICS-based control system and PLC-based controls. The process instrumentation and control for the target systems will be designed to connect to the existing machine control system to provide both safety-related and non-safety-related control, equipment protection, and monitoring [7].

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOAPP03

Instrument Data Acquisition and Controls

The data acquisition (DAQ) and control systems for the SNS FTS neutron scattering instruments were upgraded during the period from 2013 to early 2019. Additionally, three instruments at the High Flux Isotope Reactor (HFIR) are using the same DAQ and control system, with additional HFIR instruments transitioning now and in the next few years. With these upgrades, the DAQ and control system is well positioned for meeting STS instrument needs.

Each beamline has a dedicated private computer network for instrument operation and data collection, with core computing infrastructure serving all of the instruments. Common hardware and software components and tools are used to meet individual instrument needs. This toolkit-based approach helps to ensure a robust, reliable, and maintainable DAQ and control system, with the performance, flexibility, and adaptability to meet instrument needs across the suite of FTS, STS, and HFIR neutron scattering instruments.

The ICS scope for instruments includes the design and implementation of custom and commercial electronics for acquiring neutron scattering data; the, development and implementation of software for acquiring [8], processing, and managing data; the development and implementation of software and user interfaces [9] for beamline control, data collection, and experiment automation; and the design and implementation of the computing, data storage, and network infrastructure for DAQ, data reduction, and remote user access.

Conventional Facility Controls

The ICS scope for conventional facilities includes control systems for utilities and technical building automation systems. The distributed controls architecture will be EPICS. The control system design will include all controller hardware up to the process field devices, e.g., instrumentation, variable frequency drives, motor control centers, and others. The control system will consist of hardware controllers including PLCs, BACnet controllers [10], and Modbus interfaces. The design will include all software engineering for the various hardware controllers and EPICS integration. Control design effort will also include consulting on instrumentation selection to ensure compatibility for the PLC interfaces.

CONCLUSION

The PPU Project has received DOE approval for Critical Decision 3b which allows procurement of long-lead items. Procurement of accelerating cavities, cryomodules and related equipment is currently underway. The STS Project is currently in conceptual design. A conceptual design review of ICS scope was held in March, 2019. Preparations are currently underway for Critical Decision 1 which will define the project cost range and allow for preliminary design work to begin.

The control systems for these project are among the enabling technologies necessary for the projects' success. The existing control systems, and ongoing upgrade projects, position the SNS for a successful execution of these major projects.

ACKNOWLEDGMENTS

Thank you to the Proton Power Upgrade Project Team and the Second Target Station Project Team.

REFERENCES

[1] D. P. Gurd, "Management of a Large, Distributed Control System Development Project", in *Proc. 8th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'01)*, San Jose, CA, USA, Nov. 2001, paper TUDI002, pp. 55-62.

[2] EPICS, `https://epics-controls.org`

[3] S. M. Hartman, "SNS Instrument Data Acquisition and Controls", in *Proc. 14th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'13)*, San Francisco, CA, USA, Oct. 2013, paper TUPPC076, pp. 755–758.

[4] C. Deibele, D. C. Williams, and K. L. Mahoney, "SNS Credited Pulse Energy Limit System Conceptual Design", presented at the 17th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'19), New York, NY, USA, Oct. 2019, paper WEPHA092, this conference.

[5] A. N. Johnson *et al.*, "EPICS 7 Core Status Report", presented at the 17th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'19), New York, NY, USA, Oct. 2019, paper WECPR01, this conference.

[6] Control System Studio, `http://controlsystemstudio.org`

[7] D. L. Humphreys, "Target Control and Protection Systems Lessons from SNS Operations", presented at the 17th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'19), New York, NY, USA, Oct. 2019, paper THCPR02, this conference.

[8] K. Vodopivec, J. E. Breeding, and J. W. Sinclair, "The Linux Device Driver Framework for High-Throughput Lossless Data Streaming Applications", presented at the 17th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'19), New York, NY, USA, Oct. 2019, paper MOPHA156, this conference.

[9] X. Yao *et al.*, "UX Focused Development Work During Recent ORNL EPICS-Based Instrument Control System Upgrade Projects", presented at the 17th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'19), New York, NY, USA, Oct. 2019, paper TUCPR05, this conference.

[10] S. B. Webb, "Using BACnet to Integrate Conventional Facilities Into EPICS at SNS", presented at the 17th Int. Conf. on Accelerator and Large Experimental Control Systems (ICALEPCS'19), New York, NY, USA, Oct. 2019, paper WEPHA159, this conference.