SYSTEM DESIGN TOWARDS HIGHER AVAILABILITY FOR LARGE DISTRIBUTED CONTROL SYSTEMS*

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Abstract

Large distributed control systems for particle accelerators present a complex system engineering challenge. The system, with its significant quantity of components and their complex interactions, must be able to support reliable accelerator operations while providing the flexibility to accommodate changing requirements. System design and architecture focused on required data flow are key to ensuring high control system availability. Using examples from the operational experience of the Spallation Neutron Source at Oak Ridge National Laboratory, recommendations will be presented for leveraging current technologies to design systems for high availability in future large scale projects.

INTRODUCTION

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is an accelerator-driven pulsed neutron source for scientific research and industrial development. The accelerator is a high intensity H^- linac operating at 60 Hz with superconducting RF. The accelerator control system, built using the Experimental and Industrial Control System (EPICS) toolkit, consists of over 300,000 process variables on a dedicated network of approximately 1,200 nodes, including over 500 EPICS input-output controllers for controls and diagnostics, and over 100 programmable logic controllers (PLCs).

After construction, which was completed by a partnership of six US Department of Energy National Laboratories, the SNS began a simultaneous ramp up of beam power and operational hours coupled with higher availability goals. At present, the SNS has demonstrated repeatable operation at 1 megawatt of beam power (Fig. 1), and over 5000 hours of total operating time per year including over 4500 hours of neutron production time for the user program, with availability of greater then 90% (Fig. 2).

For the 2012 fiscal year, the accelerator availability goal is 90% with a 4500 hour production schedule. For the accelerator controls system, this translates to an availability requirement of approximately 99.5%

MANAGING COMPLEXITY

Large-scale, high-expense experimental science projects are increasingly undertaken as collaborative projects in

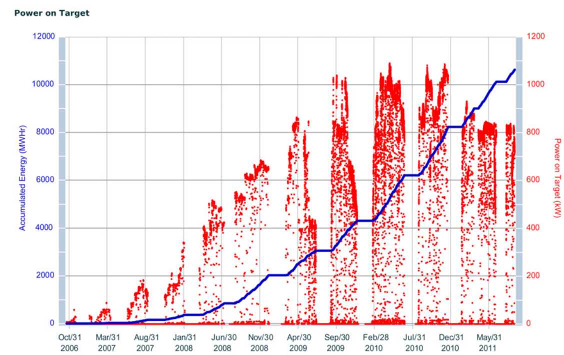

Figure 1: SNS energy and power on target, October 2006 to mid-September 2011.

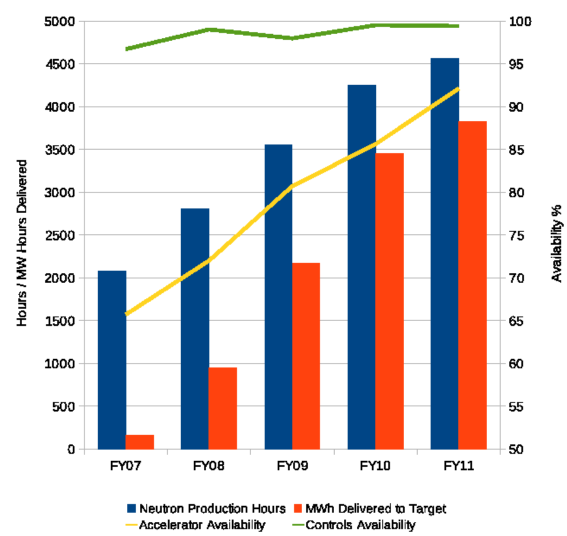

Figure 2: SNS accelerator and accelerator controls (excluding safety systems) operational performance, October 2006 to mid-September 2011.

response to funding pressures and system complexity. For the SNS, the partners were all US Department of Energy National Laboratories. In this case, there was a single funding agency, with all partners responsible to the same organizational and budgetary authority. For projects such as the European Spallation Source or ITER, there is the added complexity of partner contributors belonging to separate nations with responsibility for "in-kind" contributions rather then a central budget authority and organizational structure.

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For projects of this scope and complexity, a systems engineering approach with a holistic view of the final requirements and operational needs is critical to success. The control system serves as the interface between the various subsystems and between hardware and humans. As such, it is a key for managing this complexity. By standardizing interfaces, protocols and data handling, the control system provides the structure for bringing together the disparate parts into an overall system.

Accelerator Controls

For the SNS project, the accelerator control system group was involved early in setting standards to unify the activities of the contributing laboratories [1]. An early key decision was to standardize on a common, well developed toolkit and network protocol for use for all subsystems, namely the EPICS toolkit and the EPICS Channel Access protocol. This provided a common framework for diverse technical systems and for contributors during construction. For an operational facility, the benefit is a common set of tools and operator interfaces for accelerator controls, beam instrumentation and diagnostics, and safety systems.

Additionally, the scope for the accelerator control system was broadly conceived. The control system for conventional facility services for technical buildings, typically within the scope of the facilities or site service department, was instead included in the scope of the accelerator control system. The benefit of this decision for operations is that it becomes a simple matter to correlate, for example, the operation of a chiller or the temperature of a building with an accelerator RF structure and its impact on the beam.

Another area where the SNS control system succeeded was in the early standardization on hardware formats. Limiting the number of supported field buses and process control equipment types has resulted in simplification of long term support and maintenance. The benefit is in simpler spares management and maintenance, and fewer skills sets for which ongoing expertise is needed. Although such hardware standardization is likely to result in increased costs during the construction period, over the multi-decade life of the project, the reduced maintenance and support cost will more then offset this.

There are a few areas where early design and planning for the SNS control system has resulted in ongoing challenges for the operational period. The control system naming standard continues to be a problem. Legal names for the control system relational database are not legal in the equipment tracking and maintenance system. Names for networked devices as represented in the relational database are not compliant network host names, and it is not possible to derive the device name from a known host name. The SNS naming standard's flexibility regarding capitalization and attempts to improve readability for humans resulted in names which are neither computer parseable nor human guessable. Related to this problem is the incomplete realization of using a relational database as the definitive data source for control system tools. A lack of sufficient tools to facilitate support for early buy-in and use of the database resulted in incomplete, missing or incorrect data in the database; this still presents problems years later for control system configuration. It is critical to ensure that data entered in to the database is used from the start for actual system configuration. This ensures full investment into the system and provides the impetus to ensure data entered is correct and useful.

In recent years of the operational period for SNS, a concerted effort has been made to address control system problems that do occur at their source [2]. Review of incidents causing accelerator downtime with emphasis on identifying recurring problems and patterns has resulted in impressively high availability for the past two years. Understanding how a component, whether software or hardware, failed and how this impacted operation of accelerator systems can lead to proper fixes and long term improvements in availability.

Looking forward, an issue which needs to be addressed is obsolescence. Even though the facility has only been in operation for about five years, some custom hardware designs rely on parts which are no longer commercially available. Timing system hardware redesign is already in process [3]. At this point, industrial bus components such as VME hardware and PLCs do not appear to be a problem, or have clear upgrade paths using commercially available products. Likewise, software (such as EPICS), operating systems (Linux and VxWorks), and computing hardware (servers and workstations) have a clear path forward with reasonable compatibility available across upgrades.

The network, however, may become a problem in the future. Even after five of years of operation, the quantity of network devices on the dedicated control system network continues to grow. The initial network design resulted in a relatively flat network with a very large broadcast space for EPICS Channel Access searches. Currently, there are no significant performance issues with the network, but as the number of devices continues to increase a limit may eventually be reached. Additionally, the address space has reached a point where manual cleanup was required to allow for new devices. It would be far preferable to have the control system network more internally segmented with capacity for additional growth built in. However, such a migration would be quite disruptive at this point in the project.

Beam Line Instrument Controls

In recent months, the SNS has undertaken a review of the data acquisition and beam line controls system. Initially, this system was not included within the scope of the accelerator controls group and development took a separate path. While the accelerator control system was developed with industrial hardware (VME bus, PLCs), a mature control system toolkit (EPICS), and commercial embedded realtime (VxWorks) or open-source (Linux) operating systems, the beam line controls were developed primarily as custom software running on commodity computers using a desktop operating system, interfacing to custom hardware. Additionally, there was less standardization on hardware, software, and system design.

Operational experience indicates a greater maintenance effort is required for this system compared to the accelerator control system. A redesign of the beam line controls system is currently in the design phase. Lessons from experience with the accelerator control system, along with beam line instrument control and data acquisition systems for other neutron sources and synchrotron sources, will be used in planning the new system (see, for example [4] [5] [6]).

The design requires a systems based approach. Beam line controls integrates a number of different subsystems including sample environment, choppers, motion control, and detector systems, and must output data in a format compatible with data analysis tools. Unlike an accelerator with a central control room and an operations staff, the experiments need to be controlled by users who may not have expertise in experiment control or data analysis. Experiments are typically scripted to allow for automated control and acquisition with minimal supervision. Nonetheless, there is significant overlap in system needs and required skill sets between accelerator controls and beam line controls.

CONCLUSION

With large user facility development projects, such as a spallation neutron source or a synchrotron light source, there is a natural progression from developing and implementing controls and diagnostics for the accelerator system to the controls and data acquisition for the experimental beam line systems. Standardization in hardware and software architecture across these systems provides numerous benefits. During the many years of project operation, the greatest expense for the controls group will be people. By sharing common technologies and skill sets for both the accelerator systems and the experimental systems, a core group can support both systems. This strategy also has the added benefit of leveling of resources between the early phases of the project focusing on accelerator development and the later phases of the project focusing on the experimental user program.

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