Preliminary Design of NCSX Central Computing and Control

P. Sichta, J. Lawson, D. Mastrovito, P. Roney, K. Tindall
Princeton Plasma Physics Laboratory, Princeton, USA

Abstract - **The National Compact Stellarator Experiment (NCSX) is the centerpiece of the U.S. effort to develop the physics understanding of the compact stellarator and evaluate its potential for future fusion energy systems. A core component of the NCSX project is Central Computing and Control, which is comprised of seven elements: 1) Networking and Fiber Optic Infrastructure, 2) Central Instrumentation and Controls, 3) Diagnostic Data Acquisition and Facility Computing, 4) Facility Timing and Synchronization, 5) Real-time Plasma and Power Supply Control, 6) Central Safety and Interlock System, and 7) Control Room Facility. NCSX Central Computing will build upon the success of the central computing model of the National Spherical Torus Experiment (NSTX). Like NSTX, a key design principle for the NCSX computing system is to use commodity computing hardware, and open-source and collaborative software wherever practical. Three major software codes of this type will be used: EPICS, MDSplus, and the integrated plasma control software from General Atomics. This paper will present an overview of the primary elements of the Central Computing and Controls, illustrate the use of open-source and collaborative software, and describe the new technologies that will advance the computing and control capabilities for NCSX.**

Keywords- Control systems, Data acquisition; Timing.

I. Introduction

Operating a complex device such as the National Compact Stellarator Experiment (NCSX) [1] requires the coordinated control of more than 10 engineering subsystems and dozens of diagnostic systems. The subsystems that provide the conditions for producing the plasma and the diagnostics that record the plasma's properties operate with a high degree of synchronism. The diagnostics produce several gigabytes of data that must be cataloged, analyzed, visually presented, and archived. A control room facilitates the effective interaction amongst engineering operations, physics planning, and diagnostics staff. It also provides a location where the Chief Operations Engineer authorizes the operation of NCSX and its subsystems, whose operation can create hazards for personnel such as electrical, radiation, thermal, and stored energy.

The diverse nature of the NCSX research plan presents several challenges to a central computing organization:

- Collaborators come from many institutions, each with its own research culture.
- The collaborator's experience with computing technology including control, data recording, programming, and data analysis will vary.
- New collaborations are encouraged, ensuring that new computing and controls technologies will be introduced throughout NCSX's lifetime.
- The 10+ year operating period of NCSX is longer than the market lifetime of commercial computing products.

Given the above it is essential that NCSX offer computing and control services with the following attributes: 1) use currently popular computing components, 2) have a well-documented user interface with a user-support infrastructure, 3) be readily adaptable to new technologies, 4) have a highly modular architecture for incremental upgrading, and 5) be capable of being autonomously maintained.

This paper will describe the salient features of the NCSX networks, central controls, data acquisition, facility timing, central safety, and the control room.

II. Elements of Central Computing and Control

From the computing and controls perspective, NCSX and the National Spherical Torus Experiment (NSTX) [2] are similar machines. The NCSX computing design basis is NSTX, although certain elements of the design will be modernized to offer superior characteristics such as cost, performance, reliability, maintainability, and availability. Having a similar user environment on both machines will enhance the effectiveness of the scientific and engineering staff. Since the computing and control elements are similar to those already in the literature for NSTX, only a brief description will be included herein.

A. Networking and Fiber Optic Infrastructure

The NCSX network will be an extension of the NSTX and PPPL networks. PPPL's Computer Division (organization) will provide NCSX-specific design, installation, maintenance, and administration services to ensure that the network's infrastructure supports federal information safeguarding laws, Department of Energy guidance for cyber-security, and PPPL computer usage policies. The network will use several virtual local area networks (VLAN), as depicted in fig. 1.

Work performed under the auspices of the US Department of Energy by Princeton Plasma Physics Laboratory under Contract No. DE-AC02-76-CH0-3073.

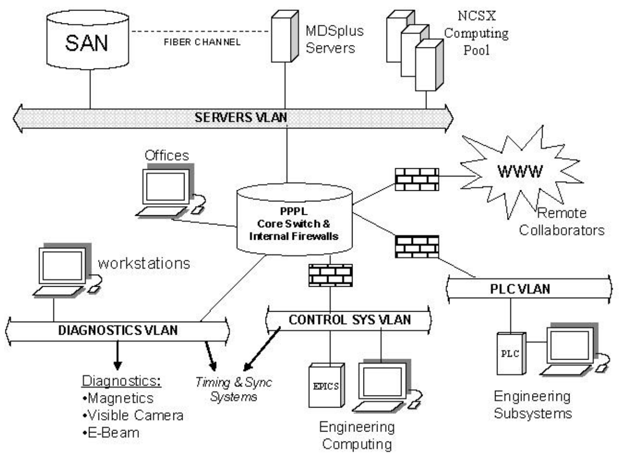

Figure 1. The NCSX network is made up up several VLANS, some with firewalls to restrict access. Remote collaborators can participate in the experiments.

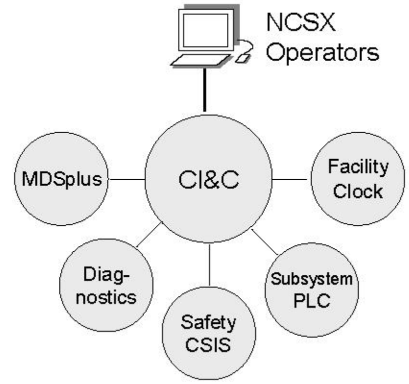

Figure 2. The Central Instrumentation and Control system provides integrated control, with interfaces to various diagnostics, subsystems, and other data interfaces.

The VLAN is a method for creating independent logical networks within a physical network. It reduces cost by allowing the physical network infrastructure (routers, switches, and fiber optic cables) to be shared among several enclaves while maintaining data security. One drawback of this topology is that any one virtual network's throughput, or effective bandwidth, is a function of the data loads being presented by the other virtual networks which share the physical media/devices. For systems that rely on guaranteed network performance (either throughput or latency) such as a safety system or PLC network, then a private physical network infrastructure is appropriate. Identifying these will be a key design consideration for NCSX.

NCSX must use fiber optic cables to connect physically-distant subsystem locations and to provide isolation to mitigate electrical hazards. A fiber optic cable infrastructure consisting of hundreds of fibers will be installed. Both multimode and single mode fibers will be used to support not only central computing as well as other NCSX interests such as diagnostics, engineering subsystems, and other special purpose applications. Although only a relatively small number of these fibers will be used for first plasma, a substantial cost-savings is achieved if spare fibers are installed at the outset of the project.

B. Central Instrumentation and Control

The Central Instrumentation and Control system (CI&C) will fulfill a number of needs such as integrated control and monitoring, central alarm handling, operator displays, and historical trending. Integrated control implies an interface with other (external) control systems and data repositories as shown on fig. 2. The method is usually through a communication protocol such as IEEE 802, OPC [3], Modbus [4], Channel Access -- the Experimental Physics Instrumentation and Control System (EPICS) [5] network protocol --, or other popular fieldbus. CI&C will also have its own input/output (I/O) and data acquisition capability, for internal controls and discrete interfaces.

The CI&C will be based upon the EPICS software. This open-source software has proven to be reliable, extensible, and compatible with many I/O, automation, and computing standards and, once a modest "learning curve" is over [6], easy to use and maintain. The EPICS user community has been active; modernizing the software, supporting new hardware, and holding frequent collaboration meetings. EPICS is used on several large DOE-funded (and non-domestic) projects so this trend is expected to continue.

Although the CI&C functions for NCSX will be the same as NSTX, there will be several improvements; foremost the operating system used for the EPICS clients and servers. NCSX will use Linux whereas NSTX relied on proprietary products Solaris (Sun Microsystems) and vxWorks (Wind River Systems). Linux does not have the real-time performance of vxWorks but that is not required for our integrated control applications. Other EPICS 'tools' will likely be upgraded to more recent versions that support, for example, web-technologies, java, scripting languages, and virtual machines. Advancements to integrate EPICS and the Model Driven System-plus (MDSplus) software [7] are progressing on NSTX [8, 9] and Korean Superconducting Tokamak Advanced Research (KSTAR) [10]. These will be directly applicable to NCSX. CI&C will also provide audio and video services for the NCSX test cell.

C. Data Acquisition and Facility Computing

NCSX will use the open-source MDSplus software in a manner similar to NSTX [11]. The Data Acquisition and Facility Computing systems will provide device configuration, control, acquisition, visualization, and an event system to synchronize processes. Back-end services include storage, management, archiving, and data analysis. There will be numerous MDSplus servers to provide researchers with access to the pool of experimental data. The data will be physically stored on project-specific disks within the PPPL Storage Area Network (SAN). The SAN architecture is scalable to accommodate all data for the lifetime of the machine.

For device configuration and control, the MDSplus framework accommodates custom device drivers and GUI (user-interface). Several programming languages are supported within MDSplus, including the efficient Tree Definition Interface (TDI) language [12] as well as Java and web-based user interfaces. For scheduling activities and synchronizing the MDSplus servers' actions with the NCSX Facility Clock (ref. next section) a "dispatcher" program will be developed. This task will be used to create shot trees, arm data acquisition devices, collect data, and log activities and error conditions. Scope, a popular MDSplus plotting program that is used to visualize two-dimensional data, will be used

D. FacilityTiming and Synchronization

A Facility Clock system will be developed to provide hardware and software synchronization services. This system is shown on Fig. 3. The hardware is comprised of an event-encoding subsystem, a clock distribution subsystem, and an event decoding subsystem. The system transmits Manchester-encoded "events" using a 10 MHz carrier. The Facility Clock link uses both twisted-pair and fiber optic media to distribute the events throughout the NCSX facility to provide synchronization on the order of a few microseconds. The Universal Networked Timer (UNT) [13] will be used to decode the events and provide a number of timing and synchronization functions. For example, an event can be decoded, followed by a programmed delay, and then a pulse is issued to trigger a transient digitizer.

Software events can be used to synchronize programs running on different (or the same) computers. Two open-source event systems are used, the MDSplus event system and the EPICS event system. The IEEE 802 network is used to distribute these events. MDSplus provides an event service that is experiment-wide. Events can be generated by multiple sources and received by multiple recipients. The EPICS event system is local within each Input-Output-Controller (IOC), of which there will be several on NCSX. Core EPICS software is capable of linking these local events across multiple IOC's, in essence creating an experiment-wide EPICS event system. The effective latency for events in MDSplus and EPICS is on the order of one hundred milliseconds, but will vary depending upon the application-specific implementation. NSTX is developing software that couples the two event systems [8, 9].

E. Real-time Plasma and Power Supply Control

NCSX will (eventually) use the DIII-D Plasma Control System [14] software (PCS) to provide integrated, real-time plasma control. This software is used on NSTX and other fusion devices. It offers a general infrastructure for waveform programming, algorithm execution, real-time multi-cpu parallel computation and interprocess communication, with analog or digital I/O. It is scalable so it can grow with the experiment's needs.

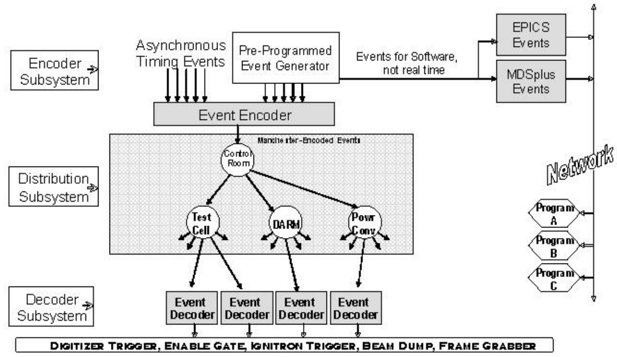

Figure 3. The general architecture of the NCSX Facility Clock System is illustrated. It is comprised of a hardware event system and a software event system. The hardware is made up of three subsystems: encoder, distribution, and decoder. There are two software event systems: MDSPlus and EPICS.

The NCSX plasma control system will be based upon the NSTX implementation [15]. Most of the NSTX's I/O equipment is based on the Front Panel Data Port (FPDP) standard [16] and was developed at PPPL [17]. The control system will acquire hundreds of input signals to control the power supplies and gas injection system in real time. Future control scenarios will likely include heating and (other) fueling systems

Since the first-plasma control requirements are simple, the relatively complex and costly PCS-based system will not be implemented for that milestone Rather two LabVIEW [18] systems with synchronized, open-loop control will be used to control the power supplies and gas injector.

F. Central Safety and Interlock System

NCSX and its subsystems and diagnostics can present hazardous conditions. Personnel are protected at the subsystem level using local safeguards; these are integrated with the Central Safety and Interlock System (CSIS). From the control room, the Chief Operations Engineer can use the CSIS to shutdown/arm the subsystems as necessary. The CSIS will provide a set of Emergency-Stop buttons to permit individuals to de-energize potentially hazardous systems. Together with a badge reader, the CSIS will be used to control personnel access to the Test Cell. A Safety PLC (Programmable Logic Controller) will be used as the foundation of the CSIS.

G. Control Room Facility

The Control Room Facility is comprised of a central control room and an adjacent computing center. The central control room facilitates the effective interaction amongst engineering operations, physics planning, and diagnostics staff. The central control room is about 2000 sq. ft. and should support about 30-40 people. WAN-capable audio, video, and data facilities will be provided to enable remote collaborators to participate in experimental operations. The computing center will hold the bulk of NCSX's networking equipment and server computers. It will also be a fiber optic cable hub location. Approximately 1200 sq. ft. is available for the computing center.

III. New Technologies

While the design basis for NCSX central computing is NSTX, some new technologies will be used.

A. Safety PLC

NCSX will be the first experiment at PPPL to use a Safety Programmable Logic Controller (SPLC). The SPLC will provide the foundation of the CSIS. The SPLC's level of safety and reliability exceeds that of a traditional relay-based, hardwired interlock system. Maintenance and upgrade costs will be substantially reduced, the operator will have system-wide view of the system from the operations console, and events and alarms can be logged.

B. OPC Communication

OPC (originally known as Object Linking and Embedding for Process Control) is open connectivity in industrial automation, as defined by a series of standards that are maintained by the OPC Foundation. Practically, for NCSX, it is a popular communication protocol that will be used to interface the CI&C (i.e. EPICS) with the PLCs used in the engineering subsystems. Most PLC vendors provide support for using the OPC protocol. Engineers within the EPICS collaboration have been using OPC for several years.

C. Upgraded Timing & Synchronization

The Timing and Synchronization system will replicate the architecture of that used for NSTX but will be upgraded to include a faster, 10 MHz clock and will use the Universal Networked Timer (UNT). No legacy CAMAC equipment will be supported for NCSX.

The UNT, which incorporates a Field Programmable Gate Array (FPGA), has been designed for NSTX and a prototype is expected to be deployed soon in order to support modern data acquisition and control systems without the need for legacy 25-year old CAMAC synchronization equipment. For NCSX, the development of the (programmable) UNT is expected to continue, especially in regard to the application program interface, the GUI, additional embedded timing and I/O capability, and network security.

IV. Status and Plans for First Plasma

This paper has described the architecture and planned features of the NCSX Computing and Control system. To reduce the cost of the project's construction phase only a portion (about 30%) of the described system will actually be implemented for first-plasma. Each of the seven elements described herein will be implemented to varying degrees, as necessary to fulfill the first-plasma objectives.

The central computing elements are currently in the preliminary design phase. Final design is currently scheduled to begin in November, 2007, followed by NCSX integrated systems testing, culminating with NCSX first-plasma.

V. Conclusion

NSTX was built using an unprecedented degree of open-source and collaborative software, partnering with the global fusion community as well as other scientific institutions. The direct 'transplant' of this software to NCSX demonstrates its inherent added value. This software has an established record of being updated by the community to incorporate new computing and control technologies. NCSX computing and controls have introduced a few new technologies, that are based on industry standards.

The design team will continue to monitor advancements within the open-source and fusion communities as well as in the computing and information technology industries in order to introduce improvements of the NCSX design.

References

[1] B.E. Nelson, et al., "Design of the National Compact Stellarator Experiment (NCSX)", Fusion Engineering and Design, Volumes 66-68 (Sep 2003) 169-174.

[2] S. Kaye , et al., "The Physics Design of the National Spherical Torus Experiment", Fusion Technology, 36, July 1999, p. 16.

[3] "OPC Specifications", http://www.opcfoundation.org/ , June, 2007

[4] "Modbus Specifications", http://www.modbus.org/ , June, 2007

[5] "EPICS - Experimental Physics and Industrial Control System", http://www.aps.anl.gov/epics/

[6] P. Sichta, J. Dong, "Startup of the Experimental Physics Industrial Control System at NSTX", 18th Symposium on Fusion Engineering, Albuquerque, NM (1999).

[7] "MDSplus", http://www.mdsplus.org/

[8] D. Mastrovito, W. Davis, J. Dong, P. Roney, P. Sichta, "Integrating EPICS and MDSplus", Fusion Engineering and Design, Volume 81 (2006), 1847-1851.

[9] W.M. Davis, D.M. Mastrovito, P.G. Roney, P. Sichta, "A Software Event Summation System for MDSplus", [1] (footnote 1)

[10] Mikyung Park, et. al., " Implementation and Initial Commissioning of KSTAR Integrated Control System", (footnote 1)

[11] W. Davis, P. Roney, T. Carroll, T. Gibney, D. Mastrovito, "The use of MDSplus on NSTX at PPPL", Fusion Eng. Des. 60 (2002), 247-251.

[12] "Tree Data Interface", http://nstx.pppl.gov/nstx/Software/TDI/TDI_TOP.HTML

[13] P. Sichta, J. Dong, J.E. Lawson, G. Oliaro, J. Wertenbaker, "Development of a Universal Networked Timer at NSTX", 21th Symposium on Fusion Engineering, Knoxville, TN (2005).

[14] B. G. Penaflor, J. R. Ferron, R. D. Johnson and D. A. Piglowski, "Current status of the upgraded DIII-D real-time digital plasma control system", Fusion Engineering and Design, Volume 71, June 2004), p 47-52,

[15] D. Mastrovito, D.Gates, M. Isaacs, J. Lawson, C. Ludescher-Furth, R. Marsala, P. Sichta, "Plasma Control System Upgrade on NSTX", (footnote 1)

[16] Front Panel Data Port , ANSI/VITA Standard 17-1998 (R2004)

[17] M.O. Isaacs, R.J. Marsala, J.E. Lawson, P. Sichta, D. Gates, "Flexible I/O and Time Stamping for FPDP", (footnote 1)

[18] "LabVIEW software", http://www.ni.com/labview/

---

[1] These were recently presented at the *Sixth IAEA Technical Meeting on Control, Data Acquisition, and Remote Participation for Fusion Research* , 4 - 8 June 2007 , Inuyama, Japan, and are being submitted for publication in *Fusion Engineering and Design*.