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# Control and data acquisition upgrades for NSTX-U

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## HIGHLIGHTS

- The NSTX-U upgrade is nearing completion, and various control and data acquisition upgrades are needed.
- The Digital Coil Protection System is a major addition which provides hardware and software to protect the magnetic coils from the complex, increased, stresses added from the upgrade.
- The increased computational requirements for the upgrade have largely followed Moore's Law, and enhancements to the infrastructure and computer hardware should maintain or exceed the previous functionality.
- Data requirements for Fast 2-D cameras have exceeded those of "conventional" time-varying signals. There has been a particular emphasis and increase in data from IR cameras.

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## ABSTRACT

The extensive NSTX Upgrade (NSTX-U) Project includes major components which allow a doubling of the toroidal field strength to 1 T, of the Neutral Beam heating power to 12 MW, and the plasma current to 2 MA, and substantial structural enhancements to withstand the increased electromagnetic loads. The maximum pulse length will go from 1.5 to 5 s. The larger and more complex forces on the coils will be protected by a Digital Coil Protection System, which requires demanding real-time data input rates, calculations and responses. The amount of conventional digitized data for a given pulse is expected to increase from 2.5 to 5 GB per second of pulse. 2-D Fast Camera data is expected to go from 2.5 GB/pulse to 10, and another 2 GB/pulse is expected from new IR cameras. Our network capacity will be increased by a factor of 10, with 10 Gb/s fibers used for the major trunks. 32-core Linux systems will be used for several functions, including between-shot data processing, MDSplus data serving, between-shot EFIT analysis, real-time processing, and for a new capability, between-shot TRANSP. Improvements to the MDSplus events subsystem will be made through the use of both UDP and TCP/IP based methods and the addition of a dedicated "event server".



## 1. Introduction

The National Spherical Torus Experiment (NSTX) [1,2] is a medium-sized, magnetically-confined, fusion experiment (plasma major radius up to 85 cm, minor radius up to 68 cm) at the Princeton Plasma Physics Laboratory (PPPL) in Princeton, NJ, USA. After operating from 1999 to 2011, NSTX has undergone a US$94 M multi-year upgrade (NSTX-U) to double the toroidal magnetic field (to 1T), the plasma current (to 2MA), and the neutral beam heating power (to 12MW) and increase the pulse length from 1.5 s to 5 s. The spherical tokamak (ST) is a leading candidate for a Fusion Nuclear Science Facility (FNSF) due to its compact size and modular configuration and NSTX-U should be able to make important contributions to developing the physics basis for an ST-based FNSF [3]. Access to low collisionality plasmas in the ST configuration is particularly important to more fully understand transport, stability and non-inductive start-up and sustainment in the ST [3].

The US Department of Energy (DoE) is funding the NSTX Upgrade with Princeton University as the management and operating (M&O) contractor. Such capital asset projects in DoE are managed through various Critical Decision (CD) Stages, and CD-4, "Approval for the Start of Operations or Project Completion" is scheduled for the spring of 2015. This is when the project moves from the construction phase to the operations phase. The computer requirements for

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**Table 1**
Overview table of IT requirements for the NSTX-U Upgrade.

- Support increased data amounts
  - More digitizer memory to support longer pulses
  - More disk capacity to keep all data online
  - Faster networks so increased data sets, especially from Fast Cameras, can be accessed by the users in a few minutes
- Intelligent Coil Protection
  - Hardware and Software real-time calculations of the increased, complex, forces on the coils
  - Thorough testing and configuration control of the systems used for protection
- Increase reliability
  - Enhance and "harden" the event messaging used to coordinate post-processing
  - Automatically alert users when specified signals are missing or out-of-range
- Increase computational capabilities
  - Increase time and spatial resolution in EFITs [12]
  - Have transport analysis available between shots (TRANSP [12,13])

CD-4 just involve activating and controlling the magnetic coils, and recording the glow of a 50KA plasma on a Fast 2-D Camera. To minimize the risk of unnecessary complications, changes to software and computer hardware used to operate NSTX-U have been minimized until this critical milestone is reached. There would then be about a 2-month period before relevant physics experiments can be carried out. By that time, additional computer hardware and software upgrades will need to be operational.

## 2. System requirements

The key, additional IT requirements for the upgrade to NSTX are summarized in Table 1.

The expected growth in data amounts and other quantities related to supporting NSTX-U is shown in Table 2. During the last experimental campaign in 2010, an average of 5 GB of data was taken and stored for a 1 s pulse (also called a "shot"). About half of this was fast camera data and half was signal data from digitizers. There were typically 40 pulses per run day, and 100 run days in a year. For the 2015 campaign we expect the per-pulse signal data to double and the camera data to quadruple, totaling 17 GB/pulse. During most of this first year of operation, NSTX-U will operate with a pulse length of 1 s, or so, but within the next few years, the pulse length will increase to 5 s as the increased capabilities of the upgrade are utilized, and the data amounts are expected to increase proportionally.

On a typical run day in 2010, there were 40 engineers and scientists in the NSTX Control Room and an additional 10–20 participating remotely. We expect the number of participants to be ∼20% higher in 2015 on NSTX-U.

The number of "pulses of interest" for years in which NSTX-U will be run at full operating capacity are expected to be somewhat lower (e.g. 2025 in 2018 vs. 3000 in 2015) because the magnetic coils will need more time to cool between pulses.

Fast 2-D Camera data [4,5] will continue to be an important source of understanding the plasma behavior in NSTX-U, both macroscopically and for edge turbulence. A key issue in tokamak and ST studies is the understanding of the transport of heat from the main plasma to the plasma material interface (PMI) — especially the divertor [6]. As such, there will be a substantial increase in the amount of IR camera data [7] taken during the next run. As shown in Table 2, the amount of camera data is increasing more quickly than signal data. Table 3 shows the types of cameras used on NSTX-U that will contribute the most data.

The Phantom cameras and the Miro 4, manufactured by Vision Research, will view the lower and upper divertors in NSTX-U. The Miro 2 color camera will view the full vessel interior during a discharge. The Santa Barbara Focalplane SBF 161 cameras will record IR data from the lower and upper divertors. The FLIR Tau 2 cameras will record IR data from the lower divertor (wide angle view) and the RF Antenna tangentially. The IDS UI-5240CP-NIR GigE Camera will be used for the Multi-Point Thomson Scattering diagnostic. The 8 Dalsa GigE Vision Spyder 3 cameras record 1D CCD arrays. The Princeton Instruments ProEM GigE cameras are used for a Divertor VUV spectrometer and a Divertor Control Spectrometer. The Princeton Instruments CCD w/PCI Spec-10 is used for an ultraviolet-visible survey spectrometer.

A major upgrade for NSTX-U in terms of manpower, capital equipment, and computing infrastructure is the Digital Coil Protection System (DCPS) [8,9]. The increased heating power and magnetic coil field strength for the upgrade have contributed to an increased need for protection of the coils and vessel hardware. The DCPS will protect NSTX-U during a plasma pulse by running a collection of algorithms involving 1200 calculations every 200 $\mu$s using real-time measurements of the plasma current and the 16 magnetic coil currents [10]. If the calculations from any algorithm exceeds a pre-programmed minimum or maximum limit, the power supplies are shut down before damage or unnecessary fatigue occurs. Significant improvements were made to the Power Supply Real Time Control (PSRTC) and the Plasma Control System (PCS) infrastructure, as well [9]. The pre-operational testing with DCPS has gone much more quickly, and been more reliable, than similar power testing on NSTX in the past. This can be attributed to good design and development methodologies and to the use of the AutoTester [11], where electrical signals are generated to simulate actual operations.

The equilibrium fitting code EFIT has always been integral to NSTX operations [12], calculating the location of the magnetic flux surfaces within the vacuum vessel as a function of time. A version that only uses magnetics [10] (called EFIT01) is computed quickly (∼2.5 min) after a pulse and a more accurate version (called EFIT02) that uses magnetics, diamagnetic loop, and Thomson electron density and temperature data is available ∼10min after the shot. Having EFIT data available more quickly allows other key NSTX-U calculations to be started earlier. EFIT is easily parallelized, so more dedicated processing power can also increase the time and spatial resolution of the EFIT data available between shots.

TRANSP [12,13] is a widely-used time dependent transport analysis code for tokamak experiments. Software optimizations and new computer hardware have reduced the time needed for a TRANSP analysis on an NSTX-U pulse from 90 min to less than 5 min. Having this information available between shots will help the Physics Operator know what control adjustments to make before the next pulse.

The time requirement for all the data to be acquired and sufficiently analyzed to inform the settings for the next shot is "soft." Naturally, the sooner results are available to the physics operators, the more time they have to consider their next steps. Circumstances vary, but generally speaking, if the physics operators have a minute or two to digest results before starting the next cycle, there are no complaints. Machine operating requirements, such as time needed to cool the magnetic coils, or to spin up the motor generators, will typically limit between-shot times on NSTX-U to 15–30 min.

## 3. Proposed IT hardware

Much of the IT equipment used during the last NSTX campaign needed to be updated for NSTX-U. For our primary MDSplus [14,15] data server the following hardware was ordered:

HP DL380 Gen9 24SFF CTO Server with x2 2.6 GHz-10-core- 20 threads

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