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ORIGINAL RESEARCH

Data Acquisition System of Neutral Beam Injector on EAST

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Abstract In order to supervise the elements of the neutral beam injector (NBI) spatially located at several places, a distributed NBI data acquisition system (NBIDAS) on experimental advanced superconducting tokamak (EAST) is developed in this paper. NBIDAS consists of field instrument and measurement devices, servers and remote data processing terminals. In order to remotely manage and monitor the field devices of the NBI system, a device management client software is also developed as the human–machine interfaces between the field devices and remote system administrators. A control signal acquisition system is developed for diagnosing these generated analog and digital signals from the NBI control system. NBIDAS based on network technologies is capable of extending system functions and upgrading devices. The detail of the architecture and implementation of the NBIDAS on EAST is discussed in the paper.

Keywords Data acquisition system · Neutral beam injector · EAST · Device management

Introduction

Neutral beam injector (NBI) is an effective and powerful device for plasma heating and current driving for the magnetic confinement fusion machine. In order to support the steady-state operation and physical researches, a high-power NBI system needs to be employed for experimental advanced superconducting tokamak (EAST) plasma heating and current driving [1]. According to the scientific study schedule of EAST, the designed NBI system consists of two beam lines which will be constructed in two stages. Each beam line is capable of 4 MW deuterium neutral beams with a design value of 50–80 keV in the beam energy, total beam power of 8 MW, and beam duration of 10–100 s [2, 3]. The first NBI beam line has finished the project commissioning, and the second is undergoing construction. The first 4 MW NBI system installed on EAST is shown in Fig. 1.

In order to supervise the NBI system in the control room, a distributed data acquisition (DAQ) system is developed in this paper. The device status and experimental results of NBI subsystems for each NBI shot have to be acquired. These subsystems consist of cryogenic system, gas supply, vacuum system, cooling water system, power supply systems and diagnostic systems [4]. The architecture and implementation of the NBI data acquisition system (NBIDAS) on EAST is presented in the paper.

Requirements of Data Acquisition

The elements of the neutral beam injector are spatially distributed at several places: EAST Hall (beam line, gas supply and cryogenic vacuum system, etc.), the first floor of auxiliary heating building (high voltage power supply), underground floor of the auxiliary heating building (magnet power supply, filament power supply, and arc power supply, etc.), cooling water room and control room. High voltage Power Supply (PS), low voltage PS and control room are in the EAST auxiliary heating building. In order to supervise the NBI system in the control room, a distributed data acquisition system (DAS) is developed to

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Fig. 1 The first 4 MW NBI system installed on EAST

Table 1 The list of analog input and digital input signals on EAST NBI

Subsystems	Analog inputs		Digital inputs
	No. of channels	Sampling rate	
Electric measurements of power supplies	44	10–50 kS/s	32
Gas supply	2	2 S/s	0
Vacuum system	3	10 S/s	0
Thermal couples	270	20 S/s	2
Water flow calorimeter	80	10 S/s	0
Cryogenic system	4	1 S/s	0
Ion source	10	1 MS/s	0
Motional stark effect	16	2 MS/s	0
Control signal acquisition	64	200 kS/s	64
Timing system	16	100 kS/s	18
Doppler shift spectrometer	2	1.2 MB/s	0
Total	511		116

acquire the signals of power supplies, gas supplies, cryogenic vacuum system, water cooling system, etc. The acquired experimental data is compressed into LZO format data for saving network traffic and disk storage. The compressed data are sent to the data server over the data network.

Table 1 lists the scientific diagnostics installed on EAST NBI. The NBI data acquisition requirements can be summarized by the maximum data rate into the archive (about 100 MB/s) and maximum annual data storage (about 2.8 TB). As for the categories of the data acquisition signals, they are grouped after their sampling requirements: (1) slow signals to be acquired continuously and independently of beam operations (e.g. in-vessel gas pressure), (2) low-bandwidth signals (up to tens of kS/s) that are acquired only during the beam on phase (e.g. electric measurements of power supplies), (3) high bandwidth signals (up to several MS/s) that are acquired on an event-driven policy (power supply measurements during ramping up phase) and (4) images (spectrometers).

Architecture of Data Acquisition System

Neutral beam injector data acquisition system is a distributed DAS. It consists of field instrument and measurement devices, servers and remote data processing terminals. The architecture of the NBIDAS is shown in Fig. 2. The field instrument and measurement devices are respectively connected to three field subnetworks: field diagnostic network, field data network and field control network. The field diagnostic network directly connects to remote diagnostic network by a speed of 1 Gbps optic fiber network link. The control server like a network router breaks the control network into two subnetworks: field control network and remote control network. The control server communicates with remote control network and field control network by two 1-Gpbs-speed optic fiber links. The data server like a network router is connected to three subnetworks. It breaks the data network into two subnetworks: remote data network and field data network. The data server acts as a data communicating bridge between data network and remote diagnostic network and provides historic experimental data to those diagnostic analysis terminals. The web server connects to control server and data server through remote control network and remote data network respectively. The remote users over the internet network may access the NBI system by browsing web pages on the web server.

Data Acquisition Systems Over the Field Network

There are two DAQ systems over the field data network. One is for acquiring electric signals of the power supplies (e.g. high voltage, arc, filament, snubber and magnet power supplies, etc.) for two ion sources. The other is the control signal acquisition system for control system diagnostics. A PXI crate houses four 16-bit 250 kS/s simultaneous-sampling cards (Model No. PXI-2022 made by ADLink) providing 64 channels for acquiring output signals of the NBI power supplies and the sampling rate per channel up to 50 kS/s [5]. The analog multiplexer is designed to enhance the signal driving capability by providing the function of one analog signal input and four enhanced signal outputs. The control signal acquisition system is a CPCI-based platform with analog and digital signal acquisition cards. A 16-bit 64-channel 250 kS/s multi-

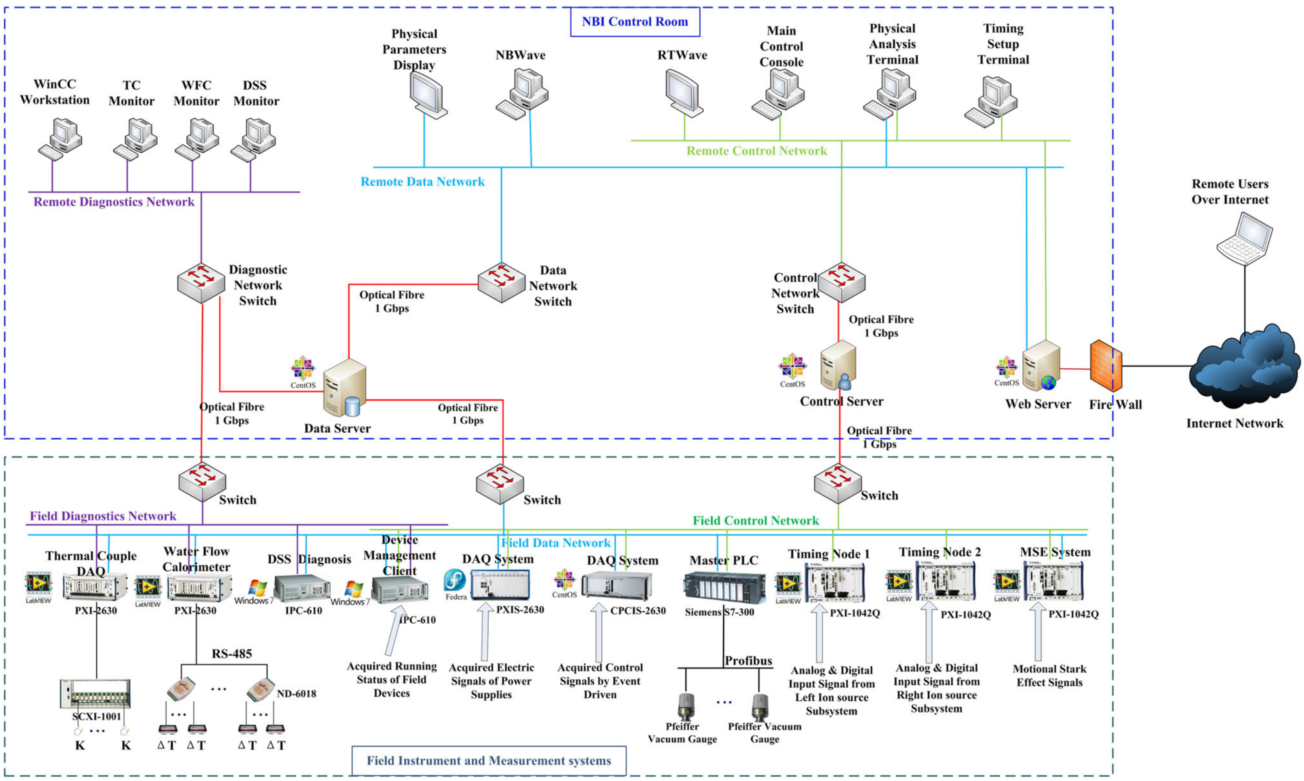

Fig. 2 Architecture of the NBI data acquisition system

function DAQ card (Model No. CPCI-9116 made by AD-Link) is adopted to acquire the analog signals generated by per Timing node. A dedicated 64-channel 10 MS/s digital input DAQ card which is developed by utilizing FPGA technology is adopted to acquire the system status signals and timing sequence signals of the NBI control system. All these signals from the field devices are isolated by the optical fibers.

Motional stark effect (MSE) DAS is developed for measurement and control of the current profile which is essential for high performance and steady state operation of the EAST tokamak. A National instruments (NI) PXI-1042Q chassis in MSE DAQ system houses two 14-bit 2.5 MS/s simultaneous-sampling DAQ cards (Model No. PXI-6133 made by NI) for acquiring 16-channel signals of photoelastic–modulators. The Thermal Couple (TC) DAQ system and water flow calorimeter (WFC) utilizing two NI PXI-2630 crates house several PXI-bus DAQ cards. The TC DAQ system monitors several hundred channels of the temperatures on the beam collimators, ion dumps, calorimeters etc. WFC collects the water flow rates and the delta temperatures between the inlet water and the outlet water through the beam line. Doppler Shift Spectrometer (DSS) of the NBI system is adopted to diagnose the beam species. Master PLC collects the pressure values in the vessel from these Pfeiffer vacuum gauges over the Profibus network and reports them to the data server and the control server.

There are two timing nodes named as Timing node 1 for left ion source and Timing node 2 for right ion source acquire the digital input signals which consist of running statuses of the field control devices, positions of the calorimeters, switch ON/OFF states of valves and so on. The Timing nodes interlock the NBI experimental operations according to the digital input status signals and report these information to the control server. The control server stores the status information into the real-time database and updates the remote monitoring terminals at the given frequencies.

All the DAQ systems over the data network send the acquired data to the data server. The data are compressed into LZO format data to save the network traffic and disk storage. The data server receives these data and stores them into an experimental database. The remote experimental analysis users may retrieve the historic experimental data by connecting the data server over the data network. The DAQ programs running on the PXI platforms are developed with LabVIEW 2010. The DAQ system for acquiring signals from power supplies and DAQ system for control signal diagnosis are developed in C++ language under the Federa 14. The DSS DAQ program is a commercial software, its data processing program is developed with Matlab 2010 under a Windows operation system.

Device Management Clients

In order to remotely manage and monitor the experimental devices of the NBI system, a device management client (DMC) software is developed as the human–machine interfaces between the field devices and remote system administrators. The device management software based on network technologies communicate with main control server. The field DMCs are simultaneously connected to the field control network, the field data network and the field diagnostic network. So, the field DMCs may monitor and control the field devices over these three networks. The DMC client software developed in C/C++ language has been deployed to the distributed field control computers under the Windows operating system. The device management software ensures equipment security and promotes the progress of the experimental operation smoothly. It solves the problem of remote management and monitoring of field devices during EAST NBI experimental campaigns. It is easy for system extension and device upgrading to analyze the fault and alarm information with the DMC software when a problem occurs.

Remote Data Processing Terminals

Remote data processing terminals in the control room are connected to the main control server or main data server. Main control console (MCC) connected to the remote control network provides easy and flexible operational methods for operators to remotely operate the NBI device [6]. It provides user graphical interfaces for users to setup or modify the parameters of power supplies and physical operational parameters. The field device status and configuration parameters are displayed on the main window in real time. When the configuration is changed, the validity and rationality of the data will be verified. Timing setup terminal connected to the remote control network provides user interfaces for modify timing sequences and trigger parameters for the field devices. Timing sequence waveform generation provides a visual method to view the timing-related control logics [7]. The LabVIEW programs running on the timing setup terminal also brings the advantages to administrators to remotely develop and debug real time programs. Experimental analysis terminals connected to remote data network provide experimental data analysis and query tools for operators and physicists by running software on this terminal, such as NBWave (an experimental waveform display software by retrieving data from the data server), RTWave (an experimental waveform display software by retrieving data from the real time status database of the control server), etc.

All the terminals connected to the remote diagnostic network may directly access the field devices over the diagnostic network. WinCC workstation is directly connected to the upper computer of the master PLC over the diagnostic network, fetching the operation details of the power supplies, cooling water system, cryogenic vacuum system, and so on. It provides user graphic interfaces to remotely manage the field devices which are connected to the PLC system. TC monitor and WFC monitor provide user graphical interfaces for operators to monitor several hundred temperatures of beam collimators, ion dumps, calorimeters, etc. The flow rate and delta temperature of the cooling water system are also displayed in the terminal. There are several programs running on the terminal to calculate the beam power and process diagnostic data [8]. DSS terminal is used to remotely access the field spectrometer by a remote desktop connection. It provides the diagnostic data about the beam species.

Results and Discussion

NBIDAS had been deployed on the test stand for EAST NBI in 2010. The objectives of beam power 4 MW, beam energy 80 keV and beam pulse width 100 s have been achieved independently with the NBIDAS on the test stand. The project commissioning of the first EAST NBI is accomplished by using NBIDAS in 2013. During the project commissioning, two ion sources (Left and Right ion sources) have reached the following experimental operation parameters respectively, beam energy 52 keV with current 22 A and beam energy 40 keV with current 25 A, and beam pulse width 1 s. Figure 3 shows the experimental waveforms of Left ion source at shot 650. The

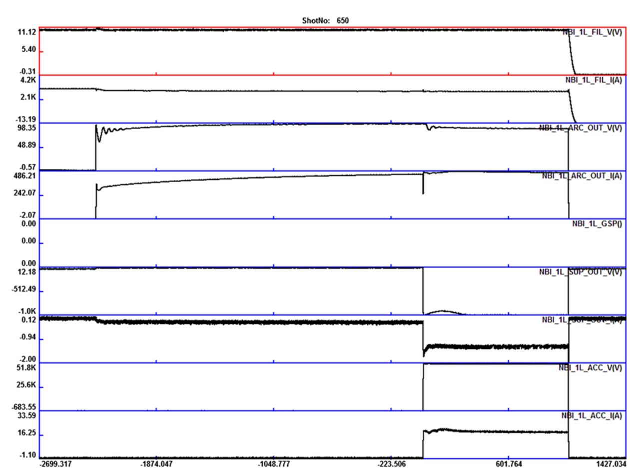

Fig. 3 Experimental waveforms of left ion source of EAST NBI (Shot No. 650)

experimental result displayed by the NBWave shows when the operations of filament power supply (NBI_1L_FIL_I and NBI_1L_FIL_V) and arc power supply (NBI_1L_ARC_OUT_I and NBI_1L_ARC_OUT_V) are stable, an ion beam with energy 51.8 keV and current 18.8 A is extracted by switching on Accel. PS (NBI_1L_ACC_I and NBI_1L_ACC_V) and Decel. PS (NBI_1L_SUP_OUT_I and NBI_1L_SUP_OUT_V) simultaneously. The beam extraction is interrupted by the interlock and protection system at the time of spark occurrence on plasma grids, and its pulse width about 1 s. It is demonstrated that NBIDAS meets the requirements of the functions of the remote monitoring and data analysis.

Conclusion

A distributed data acquisition (DAQ) system is developed to supervise the NBI system in the control room. The architecture and implementation of the NBIDAS on EAST is presented in this paper. NBIDAS acquires the device statuses and experimental results of NBI subsystems (cryogenic system, gas supply, vacuum system, cooling water system, power supply systems and diagnostic systems, etc.) for each NBI shot. Experimental results demonstrate that NBIDAS meets the requirements of the functions of remote monitoring and data analysis.

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