Operational Experience of SST1 NBI control System with prototype Ion source

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Abstract. This paper presents operational experience of integrated control of the arc-filament and High-voltage power supply of Steady State Tokamak (SST)-1 NBI system using Versa Module Europa (VME) system on prototype Ion source. The control algorithm is implemented on the VxWorks operating system using 'C' language. This paper also describes the operating sequence and controls on power supply system. Discharge and Filament power supplies are controlled in such a way so that necessary discharge current can be available in Ion Source. The discharge current is controlled by manipulating the filament current. Close loop control is implemented on each filament power supply with feedback from Discharge Current to control the overall discharge inside the ion source. Necessary actions for shut OFF and subsequent Turn ON are also taken during breakdowns between the Grids of the ion source. Total numbers of breakdowns are also monitored. Shot is terminated, if the breakdown count is higher than the set value. This control system can be programmed to restart High-voltage power supply within 5mS after breakdown occurs. This control system is capable to handle the all types of dynamics in the system. This paper also presents results of experiment.

1. Introduction

A Neutral Beam Injector (NBI) System provides additional heating to the SST-1 Tokamak, it is designed for injecting 1.7MW power into the plasma. As a first step in the development, the NBI system with a prototype ion source has been commissioned and operated. The 1st stage experiment focused on tests of the integrated control and electrical sub-systems. A filament based Prototype hydrogen positive Ion Source was used on the NB test stand at Institute For Plasma Research (IPR), India. The test stand also comprises of essential components such as the Vacuum system, Gas feed system, some diagnostics and the data acquisition system. The beam was terminated on an Interceptor Plate with a few thermocouples for diagnostics.

The Control system for NBI has been developed using a combination of Programmable Logic Controller (PLC) and a VME Based system [1]. The Data Acquisition system is built with VXI (VME Extension for Instrumentation) based hardware. All power supply signals including the signals of Discharge-Filament power supply signals are acquired on the VME system and diagnostics signals are...
acquired in the VXI system. The VME system is referenced to the accelerator potential, up to 80kVDC. Subsystems, e.g., Gas Feed, Vacuum, Cryogenics, Cooling Water, etc. are controlled from a PLC. The Computers with Windows operating system are used for data-acquisition with VXI and human interface of the VME based control system. The Control and data acquisition software has been developed in the C++ language with virtual instrumentation library.

2. Various Sub-Systems of NBI control.

The SST-1 NBI Control system is a distributed control system split into various subsystems based on their functions. Sub-Systems can be controlled individually. Each of these sub-systems is also interfaced with the master control system. Various Sub-Systems and their primary functions are as described below. (1) Discharge-Filament Power Supply [2] Control: takes care of their health. It is also responsible to set parameters of Discharge-Filament power supply and monitor the operation. It acquires operation data of Discharge-Filament power supplies and also controls it. (2) Regulated High Voltage Power Supply (RHVPS) [2] Control: This system is used for application and control of high (acceleration) Voltage. It receives signals from central master control system for the sake of time synchronization. (3) Vacuum System: controls the external vacuum system (comprising of rotary and turbo-molecular pumps), (4) Water Cooling system: monitors water cooling circuit, (5) Gas feed system control: controls the gas feed valves to the ion source. (6) Beam line Systems takes care of safety of Beam line component. It also control the size of beam injected in to the Tokamak plasma by proper opening of V-Target. In present experiment at NBI test stand an interceptor plate made of copper blocks was used as both as a beam dump and calorimeter (7) Diagnostics System involves the thermocouple data acquisition system and the Doppler Shift Spectroscopy (DSS), and (8) Timing System: This provides timing synchronization of all subsystems of NBI. The statuses of the systems (3, 4 and 5) are vital to the operation and safety system of the NB System. A PLC is used for control of these systems, which is interfaced with the main controller.

In addition, various interlocks and safety systems, implemented on hard-wired logic, takes care of personal and equipment safety. The VME based controller is configured as the central control system and performs the managerial tasks, check readiness of all subsystems and establish communication with subsystems.

3. Hardware architecture.

The overall architecture of the SST-1 NBI control system is schematically shown in Figure-1.
The system has a central VME based control system, located inside high voltage deck. This system is connected to the Accelerator Voltage (from the RHVPS), is referenced to the high potential of the RHVPS. The reference potential of the electronics swings between Zero (ground) and the Accelerator potential. Control signals from the VME controller are isolated with fiber optic links. The wiring of the system needs special care in order to reduce transients arising within the system associated with the high voltage swings.

The VME based CPU has been loaded with real time operating system (Vx-works). In the VME chassis, several modules are used to perform various tasks, like analog signal acquisition, analog signal generation, digital commands and status information. A Windows-NT based control PC, located in NBI control room is connected to VME based control system for the operator interface.

The RHVPS System is located away from Main control system. So this system has its own localize control and exchange only operational and synchronization signals with the main control.

4. Software
The software of SST-1 NBI control system was developed using VxWorks real time operating system integrated development Tool. VME CPU having real time program and control algorithms and control loop logic are developed in C/C++ Language. Multiple processes are run in parallel, (based on a priority enabled scheme). Basic Control software flow is shown in Figure-2.

Figure 2. NBI Control Software flow diagram
GUI software for operation of NBI was developed in C++ with Virtual Instrumentation software library. Windows NT platform is used for operation of NBI. Figure-3 shows operator panel as displayed on the control PC. The NBI operational parameter such as Discharge Voltage and Current, filament Voltage, Shot duration, maximum number of Breakdown etc. can be set from the front operator panel. Acceleration voltage can be set from local RHVPS control.

![Figure 3. HMI Console](image)

5. Timing and Control algorithms

The Central VME based control generates a timing sequence for various NBI tasks as shown in Figure-4. The interlock check is done as the system starts. The gas feed system is started well in advance, as its equilibrium time constant is large. As the Filament and Discharge Power supplies are activated, the filament system is started 20 Sec before the extraction of beam, at the same time VXI based Data acquisition receives a trigger from central control system. Discharge is started one second prior, so as to stabilize the discharge. After the discharge current is stabilized, the extraction voltage with notching is applied to extract the beam. Breakdowns between the Grids are common phenomena during the conditioning of an ion source. In case of breakdown control shuts OFF Discharge power supply and Accelerator power supply (RHVPS). After a gap of 5ms both the systems are restarted simultaneously. The Control system monitors the number of breakdowns. If in a particular shot, number of breakdowns reaches its maximum value, the shot is terminated. The maximum allowable breakdowns can be set by the operator. The Centralized control takes care of the above timing sequence automatically, when the shot is started.
The control system also provides a real time control of Discharge-Filament power supply. It acquires data form Discharge and filament power supply continuously and applies a close loop PID control for controlling Discharge current. The discharge current is controlled by manipulating the filament current. A Closed loop PID control is implemented on each filament power supply to maintain a steady total discharge current in the ION Source.

6. Operational results

A prototype ion source was used for commissioning of the control system and testing of data-acquisition system. This experiment setup has been described in earlier publications [3]. The VME based control system is capable of handling various types of dynamics generated in system. As Control system floats on a high potential during breakdown the reference point of control system varies very fast. Despite of this variation in reference, the operation of control system remains stable during such variation. Typical shot data of Discharge current variation during breakdown is presented in Figures -5 and 6. Figure-5, shows variation of Discharge current in absence of PID control, while in Figure-6, shows the effect of application of PID control, as seen in the figure the discharge current almost remains stable. Figure-7 shows variation in discharge current for a single breakdown. Figure-8 shows discharge current variation for a shot with multiple (Ten) Breakdowns. These two figures depict the performance of control over the discharge current.
7. Conclusion
The Control System of the SST-1 NBI has been developed and tested with Prototype ION source. It is capable of handling all critical tasks related to timing and synchronization of the sub systems. The present algorithm assumes the control of electrical parameters of the ion source, gas flow, extraction, breakdown, etc. are not taken into account. The control algorithm is able to maintain the total current within about 10% of set level next level of experiments will target better band of control.

References
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