GA–A26427

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This is a preprint of a paper to be presented at the 36th Symposium on Fusion Engineering, May 31 through June 5, 2009 in San Diego, California and to be published in the Proceedings.

Work supported by
the U.S. Department of Energy
under DE-FC02-04ER54698

GENERAL ATOMICS PROJECT 30200
JUNE 2009

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Design of the DIII-D Top Level Power Supply Control System for an Eighth Neutral Beam Ion Source*

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Abstract— **The DIII-D project will be commissioning an eighth neutral beam ion source during CY09. Part of this effort includes returning one of the neutral beam power supplies (NBPS) to full operation. For the past 10 years, the high voltage DC portion of this system had been used to power gyrotrons in the DIII-D electron cyclotron heating system. The idle filament, magnet, arc and suppressor power supplies will be refurbished using their existing technology. The modulator/regulator for the accelerator (plasma) grid voltage is being upgraded with new controls. Interlocking and coordination of the individual supplies within the NBPS is performed by the local control station (LCS). The new design of the LCS will be presented. The current implementation of the LCS is characterized by discrete relay and CMOS logic and the use of CAMAC interfaces to the neutral beam control and data acquisition systems. These older and difficult to maintain components will be replaced with an Ethernet connected programmable logic controller and a field programmable gate array design for timing functions. Operator interfaces will change from hardwired switches and panels to graphical user interfaces on multiple screens with the capability for remote monitoring and operation. Due to schedule constraints, some of the more reliable solid state circuits in the LCS will not be immediately replaced, but an easy migration path is mapped that will cost minimal downtime once the eighth source is in operation. This project is expected to result in a viable prototype for upgrading each LCS in the other seven neutral beam power systems at DIII-D.**

Keywords: power sypply; controls; neutral beam

I. INTRODUCTION

The Neutral Beam Injection System (NBIS) power systems for seven of the eight existing ion sources (Fig. 1) each comprises five power supplies and supporting equipment. The filament and arc supplies are high current dc supplies that power the arc chamber of the source, producing the deuterium ions to be accelerated into the DIII-D plasma. The Decel supply, also referred to as the Suppressor supply, is a lower current supply that connects to a grid that suppresses back streaming electrons from the neutralizer. The magnet supply drives a bending magnet that diverts the relatively low fraction of deuterons and other species of ion that are not neutralized in the neutralization gas chamber. This action is required because non-neutrals at the injection energy would be deflected as they pass through the plasma confining fields while entering the machine and damage components. The ions are accelerated by the plasma grid power supply. This is a voltage regulated supply that outputs up to 90 kV to create a gradient between the plasma grid and the output point of the beamline structure at ground potential. The plasma grid supply is usually referred to as the modulator/regulator (MR), a consequence of its design as a series pass voltage regulator. A sixth element in the ion source, the gradient grid, is operated from a voltage divider off the plasma grid supply.

Supporting systems include 12.47 kV AC switchgear, a transformer-rectifier set with a tap changer, transient compensation capacitor bank, high voltage crowbar, and water cooling.

The coordination and interlocking of these supplies and support equipment is done by our local control stations (LCS). They are of two types among the seven operating ion sources, Transrex and Universal Voltronics Corporation (UVC). The eighth ion source will be operated by a UVC power system that has seen over 10 years service to our electron cyclotron heating systems, although it was originally built for supporting a NBIS source. The LCS for this power system, UVC #7, is the subject of this upgrade (Fig. 2).

II. LCS FUNCTIONS AND REQUIREMENTS

LCS high level functions are to (1) coordinate operation of the power supplies and support equipment, (2) provide a graphical user interface (GUI) for the supplies and equipment, and (3) protect equipment. The LCS does not perform a personnel protection function. This function is performed by an existing hardwired interlock system using Kirk locks, door switches and procedures. These devices are just monitored by the LCS.

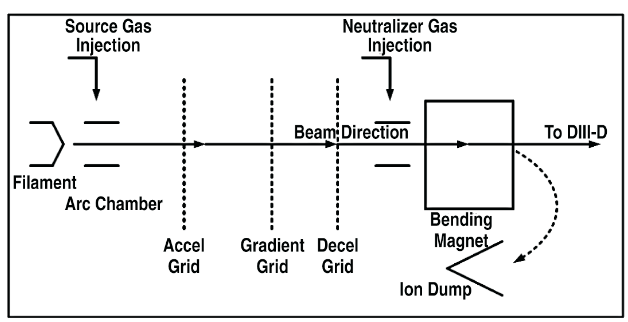

Figure 1. Neutral beam elements connected to power systems.

*This work was supported by the US Department of Energy under DE-FC02-04ER54698.

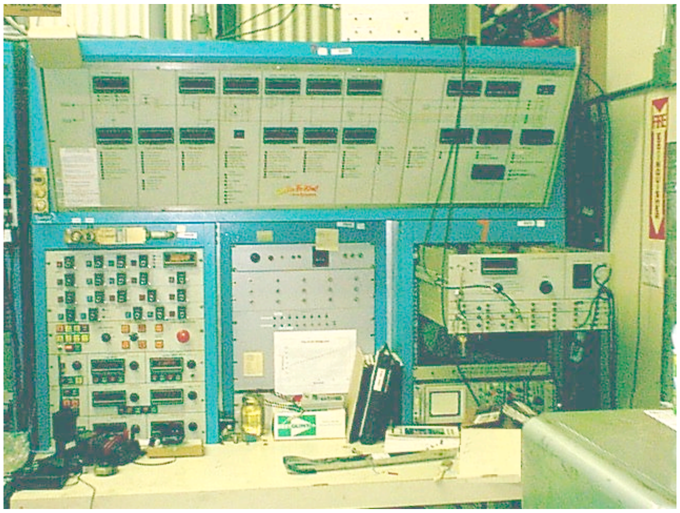

Figure 2. Photograph of the original LCS #7.

The LCS controls the sequence of turn on, the values, and the firing of all power supplies attached to the neutral beam source. It manages protection of the systems by checking door interlocks, Kirk key interlocks, and water interlocks. The timing for arming and activation, and the fault handling are also done at the LCS. There is a display to show several critical voltages and latched faults, which may have stopped system operation. The latched faults can be reset to restore the system to operation.

The LCS can be operated remotely by the neutral beam system operators using a computer interface in the main operations control room via Ethernet.

There are several timescales involved in the NBIS power system. Checking door switches and water flow is a slow task, as these are things that will only change in a 1 s time frame. Power supply faults and over-current responses are on a 1 ms time scale. HV control of the MR and the suppressor voltage are 10 to 100 µs responses, including firing the crowbar in 5 to 10 µs on detection of failure of the MR interlock systems to protect the source.

These design and performance requirements drive the design of the new LCS and are documented in interface control documents (ICDs) for every interfacing system, whether power supply or support system. The interfacing systems are shown in Fig. 3.

Other design requirements have been imposed by budget and schedule constraints. Most importantly, the LCS recommissioning needed to be completed in time to support physics operations for early FY10. This necessitated some compromise in what components of the old LCS would be replaced or retained. Before final design, it was decided that some interfacing connections would be retained as well as some fast protection circuits. The design approach is to segregate these legacy devices and interfaces to facilitate rapid replacement as a future upgrade. The time from project start to final design was set at 8 months with a 4 month construction schedule. We have a low tolerance for schedule risk as this work supports a DOE milestone. Therefore technical risk was kept low as well.

III. Design Solution for LCS

The importance of system reliability and maintainability led us to replace the components of the LCS that were most likely to have reliability problems. Primary among these is the relay logic system. A programmable controller of the type commonly used on our project was chosen for this task. The series 90 PLC from GE-Fanuc is Ethernet connected to interface with the neutral beam control computer and a General Electric Co., Intellution™ GUI solution. The beam control computer connection replaces the previous CAMAC-based connection. The PLC program was developed from detailed analysis of the relay logic diagrams as marked up in service. A dual path verification trace technique was used to assure that the PLC logic replicates the documented function of the relay logic. The PLC should provide a scan time from I/O update to logic solve to I/O update in less than 2 ms.

The GUI deployed at the LCS consists of a computer and three 22-in. screens. It is operated by a single computer and replaces the functionality of the original hardware user interface that used many buttons, lamps, set point dials, and panel meters. The lower situated screen is at the primary operator's position with the other two above for display of screens that are not cycled through often such as the top level systems status screen shown in Fig. 4. Other lower level screens show status of individual supplies, enable the setting of supply parameters, alarm levels and alarm details. The Intellution™ software will also provide the new capability of trending and alarm handling to the LCS.

In addition to the Intellution™ GUI a single hardwired panel is included to report in real time the ready, armed, and energized status of four power supplies and two gas injection circuits. This is a convenience to observe behavior particularly when the injected beam is modulated at up to 100 Hz, which the GUI is too slow to catch.

The second installed computer in the new LCS will be primarily performing functions such as providing access to online system documentation, PLC programming interface, and an X client to view waveforms from the NBIS data acquisition system. Online documentation includes hyperlinked Excel wire lists. The X client is also able to display the Borland-Kylix™ operator interface screens previously available only to the NBIS operators in the DIII-D control room.

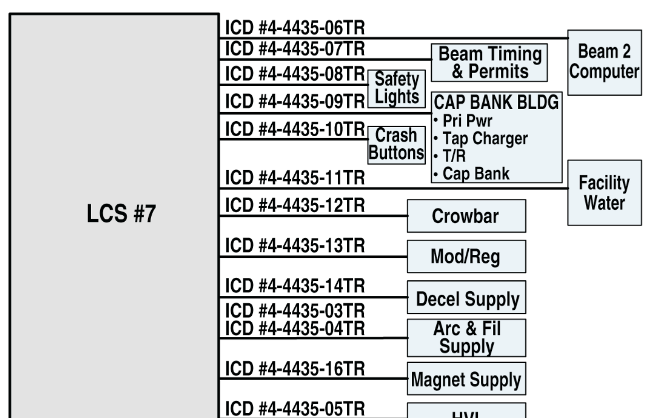

Figure 3. Context diagram of LCS showing the interfacing systems.

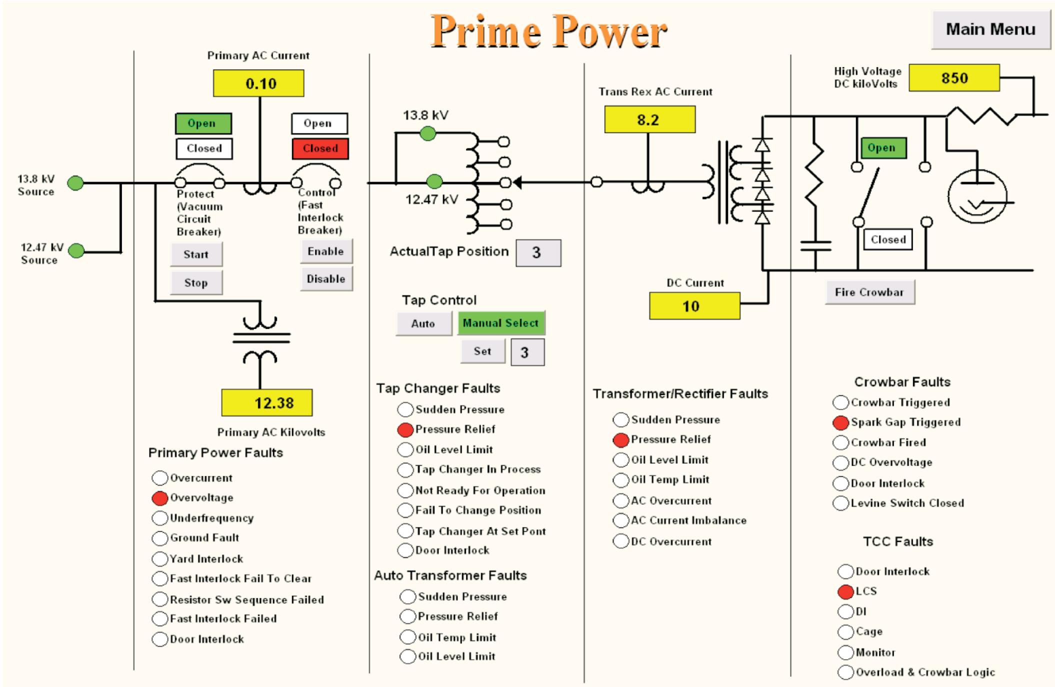

Figure 4. Top level systems status screen for the prime power.

The interface to the plasma grid supply (MR) has been completely redesigned due to the fact that the MR control system (at that power supply) was redesigned as part of the overall recommissioning effort for the eighth ion source. We use new interfaces appropriate to the speed requirements between the two systems. The new MR controls use a PLC as well for basic interlocking. Therefore, we use a Profibus link between the MR and LCS PLCs to transfer information with low speed and nondeterministic requirements. Profibus ensures that the information is actually delivered, which may not be true using the plant Ethernet. Discrete state signals requiring real time exchange, such as the “MR ready” to LCS and energize gate from LCS, are implemented using fiber optic transmitters and receivers. The object of the optical isolation is to attempt to eliminate as much possibility of noise between systems which is problematic in the current local controls for all beam lines. High speed requirement analog signals are exchanged using analog links produced by Palomar Scientific Instruments. Signals transferred in this way include voltage read back of the plasma grid and gradient grid voltages and currents. The real time analog requirements for these signals are imposed by the load (ion source) protection requirements. The MR interface is built using a 3U eurocard cage. At the LCS end, the card cage also houses redesigned NBIS timing components and a new hardwire interlock relay card that functions as a backup to certain critical PLC interlocks.

A block diagram of the LCS is presented in Fig. 5. Control components are shown shaded.

The monitor panel is a legacy retained component containing signal conditioning for fast analog signals, limit comparators for protection interlocks, and other analog circuits. It is being interfaced to the new LCS such that it can be redesigned as a separate project in the near future and quickly replaced. The monitor panel functions are well suited to a modern implementation with FPGA technology. In the short term, the monitor panel has been refurbished with a new faceplate reflecting its current functionality.

The block labeled GA added circuits and C, D, E cards are also legacy components that perform fast pulse timing, interlocking, and various specific added functions that have been added over the life of neutral beam systems. These added functions are arc protection, filament on time limiting, neutralizer gas interlock, magnet current isolation amplifier, plasma grid voltage buffer, and magnet current window comparator-interlock.

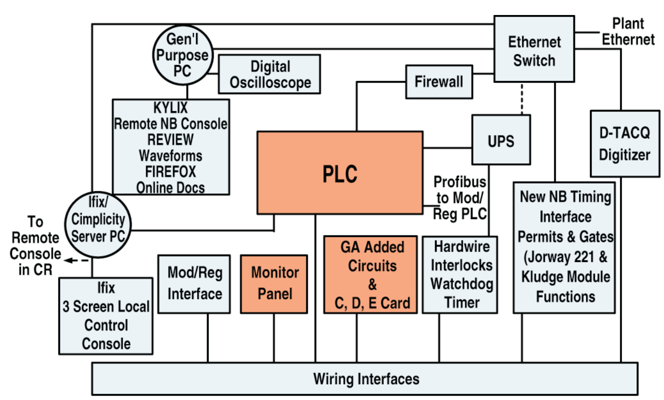

Figure 5. New LCS internal block diagram.

The new NB timing interface shown in Fig. 6 is an updated design using a Xilinx Spartan 3 FPGA and LAN91C111 Ethernet chip on an evaluation module. The LCS timing interface generates delays and durations to gate on the source gas, filament, arc, neutralizer gas and MR power supplies. The delays and durations run after a master trigger is received from the NB control area and use a 1 MHz frequency reference for counting. This hardware replaces a CAMAC-implemented version of NB timing [1]. As other UVC and Transrex systems are upgraded in the future, this current technology design will be used in those locations as well.

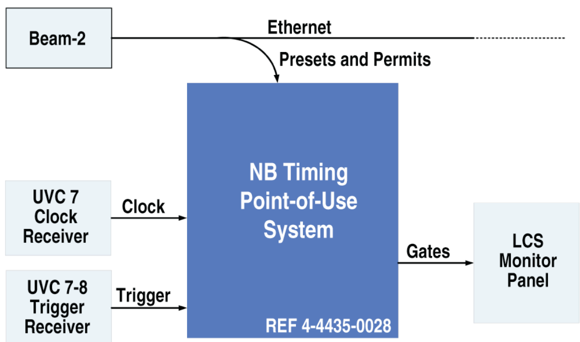

Figure 6. NB timing interface.

The delay and duration values are set pre-shot by the NB computer over Ethernet. The 1 MHz NB master clock, from a fiber optic receiver, is used to clock the unit. The timing interface achieves a resolution of 10 µs.

These are the functions of the new timing interface (Fig. 6):

1. Accept trigger and clock inputs from the UVC trigger and clock receivers.
2. Accept delay (D) and duration (W) inputs, and channel enables, from a supervisory device (computer or PLC).
3. Generate output pulses delayed from trigger event by “D” clock cycles.
4. Generate output pulses of duration (width) “W” clock cycles.
5. Generate an internal clock of 1 MHz for operation in the absence of an external clock (manually selected function).

The new timing interface was designed to have more general applicability beyond the beam systems as the basic form factor is adaptable to many installation situations.

The watchdog timer system was mandated for assurance that the PLCs in both the MR and LCS are operating. It uses one electronic timer and a rate counter to monitor two separate PLC outputs in a redundant and diverse manner. A similar set of devices is used at the MR. A self-test capability is also built into the LCS watchdog timer system as well as the function to monitor the LCS DC power supplies. A hardwired panel is the operator interface for the watchdog timer.

IV. Construction and Testing

The construction of the new LCS has started with anticipated completion in June. Testing will follow using a test plan that begins with checking of internal LCS function and proceeds to control of individual interfaced systems and finally to system coordinated operation. The construction schedule is very aggressive but mitigated by phased support for each interfacing system as schedules require. Fig. 7 shows the configuration of the LCS after completion of construction.

Conclusion

The new LCS design is anticipated to significantly improve reliability, operability and maintainability. We plan to complete the upgrades to the monitor panel and other legacy devices as time and schedule permit. Completion of this project will enable the remaining DIII-D Neutral Beam Power Systems to be upgraded more easily to this current technology, improving NBIS reliability and performance.

References

[1] G.L. Campbell and D.H. Kellman, "DIII-D CAMAC infrastructure maintenance experience and upgrade plans" Proc. 22nd IEEE/NPSS Symp. on Fusion Engineering, New Mexico, 2007.

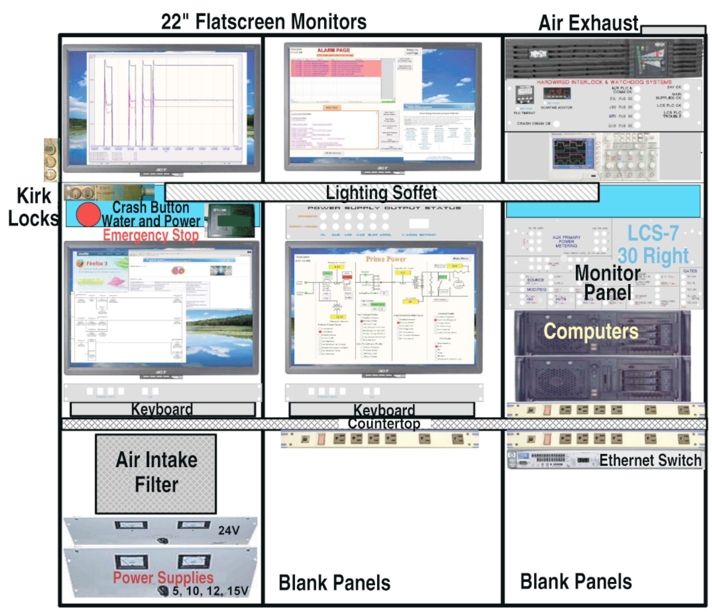

Figure 7. LCS front view after completion.