A NEW CRYOGENIC CONTROL SYSTEM FOR THE VERTICAL TEST AREA AT JEFFERSON LAB *

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Abstract

The Vertical Test Area at Jefferson Lab (JLAB), consisting of eight vertical dewars, recently received a major upgrade by replacing the original (1995) cryogenic control system. A new, state-of-the-art, distributed control system (DCS) based on Programmable Logic Controllers (PLCs) was installed and commissioned. The new system increases facility throughput, reliability and cryogenic efficiency, while improving safety. The system employs a touchscreen graphical user interface and a highly redundant architecture on an Ethernet backbone.

JLAB VTA FACILITY

A significant component of JLab's SRF R&D activities is cavity testing and characterization. This is performed in the Vertical Test Area (VTA): a unique facility designed for testing and measurement of SRF cavities in superfluid helium. The VTA consists of eight dewars, six are fitted with movable radiation shields, which permits high power testing of cavities without personnel exposure to ionizing radiation, see Fig. 1. Cavities can be tested in the VTA at frequencies from 325 MHz to over 2 GHz, and at input power levels up to 500W. In addition to cavity testing, the VTA also supports other cryogenic tests of SRF-related components such as vacuum feed-throughs, mechanical and piezo-electric tuner mechanisms, and material electrical and thermal characterization (e.g., thermal conductivity, RRR, and T c measurements).

The VTA dewars are supplied with liquid Helium (LHe) from the Cryogenic Test Facility (CTF), which can supply 4K LHe at the rate of about 150 L/hr continuously and up to 3 times that rate transiently. Dewars are pumped to sub-atmospheric pressures in order to achieve temperatures as low as 1.9K, using a vacuum pump with a capacity of about 7 g/sec. Lower temperatures can be reached (at correspondingly lower mass flow rates) using dedicated low-pressure vacuum pumps. Multiple dewars can be pumped down simultaneously, in accordance with system capabilities (defined by vacuum pump mass flow limits). All Helium used in the VTA is returned to the CTF where it is purified of any contaminants (most notably nitrogen) and re-liquefied.

The VTA dewars are instrumented with thermometers, LHe level sensors, and pressure transducers, and are controlled via interlocked electro-mechanical valves, which prevents damage to or contamination of the CTF Helium supply. Some functions, such as dewar LHe filling, pumpdown, and warmup, are computer controlled, while others are performed manually. A complete test cycle for the larger (850 liter capacity) dewars can be accomplished (warm-to-warm) in 36 hours or less. Smaller dewars (100-200 liter capacity) can be cycled in 8 hours (one shift). The combination of automated and interlocked control, along with efficient cryogen and thermal management, yields a facility with an SRF cavity test throughput unequalled anywhere in the world [1][2].

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Figure 1: JLab Vertical Test Area (VTA).

CONTROL SYSTEM OVERVIEW

The existing control system has over 20 years of successful operations. The availability of parts for maintenance and the difficulties encountered when planning seemingly simple system improvements led to the decision to replace the original custom-built electronics with modern PLCs using touch-screen user interface.

Upgrade Goals

The following goals guided development of the new control system:

1. VTA downtime during the upgrade to be minimized.
2. A graphical display of the time history (temps, pressure, LHe level) for each dewar to be provided for the operator.

3. Programs for each dewar include auto qualify, fill (atmospheric & sub-atmospheric), pump to 2K, maintain level (2K and 4K), and warm up.
4. User/Operator ability to use "Text Based Plan Scripting", where a simple sentence describes dewar fill and pump operations (eg. fill and pump dewar 8 to 800 liters at 2K)
5. System and dewar status available via web pages inside the JLab firewall.
6. A robust architecture designed to withstand single-point failure.
7. Improve electrical safety by replacing all 120Vac I/O with 24Vdc I/O.

CONTROL SYSTEM HARDWARE

Allen-Bradley ControlLogix PLCs provide the I/O interface and processing logic for the system. Allen-Bradley PanelView touch-screens provide the user interface (see Fig. 2). The reliability, ease of programming, compatibility with existing systems, and total cost of ownership were deciding factors in these choices. Each dewar has a dedicated processor. There is also a supervisory "System" PLC that coordinates multiple dewar operations and shared resources (e.g .
CTF supply and return valves, low-pressure helium pumps).

In order to improve the electrical safety of the system, all I/O was converted to 24Vdc. This required the replacement of various 120Vac actuators, limit switches, etc.

In order to minimize the disruption to ongoing SRF operations, dewars were taken out of service one at a time and upgraded. This required design and implementation of a custom FPGA that facilitated communication between the new PLCs and the pre-existing custom hardware. Furthermore, existing cables between the field I/O and the controls were re-used (see Fig. 3).

As soon as each dewar control system was upgraded, the cotrols were commissioned by way of an Operational Acceptance Test (OAT) to ensure proper services (i. e. electrical, pneumatic), followed by a Functional Acceptance Test (FAT) to validate the operation of individual I/O and related interlocks. After both OAT and FAT were successful, a final operational commissioning was accomplished that consisted of a complete, automated cooldown and warm-up cycle. Dewar level sensor calibration was included in this evolution. Once the dewar is returned to service, the next scheduled dewar is taken out of service and the upgrade sequence was repeated.

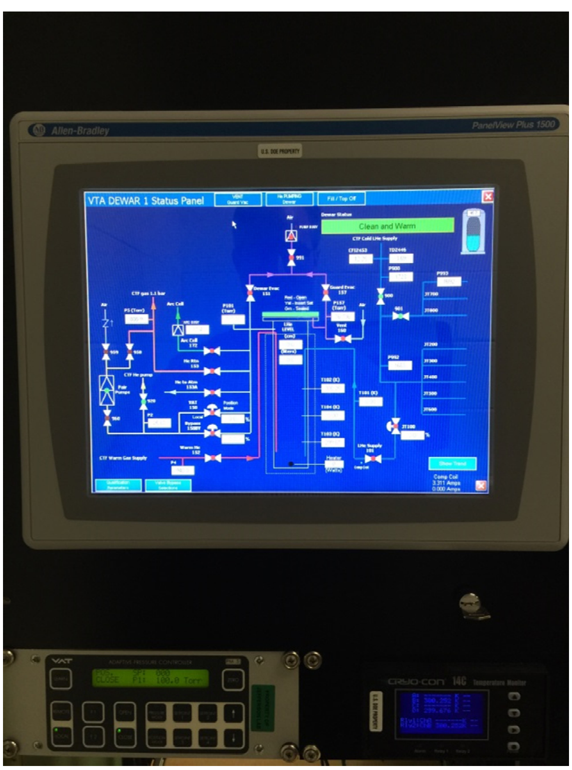

Figure 2: Dewar control HMI.

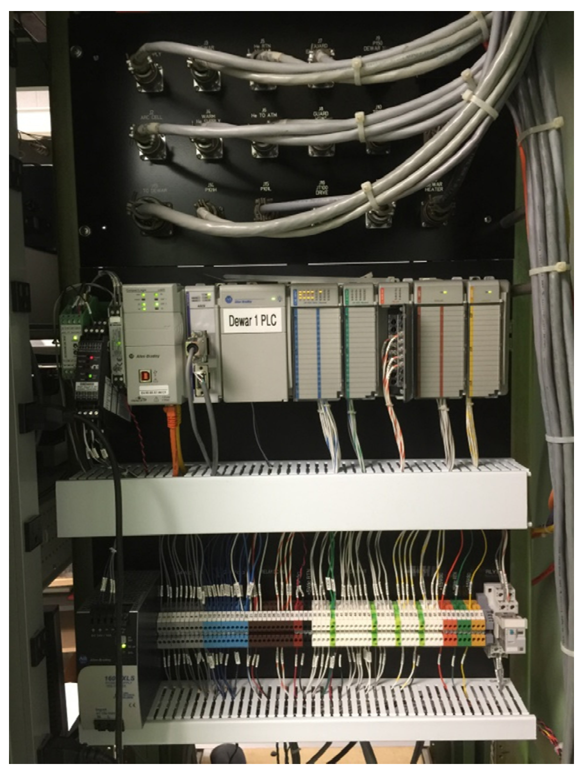

Figure 3: Dewar control PLC and I/O.

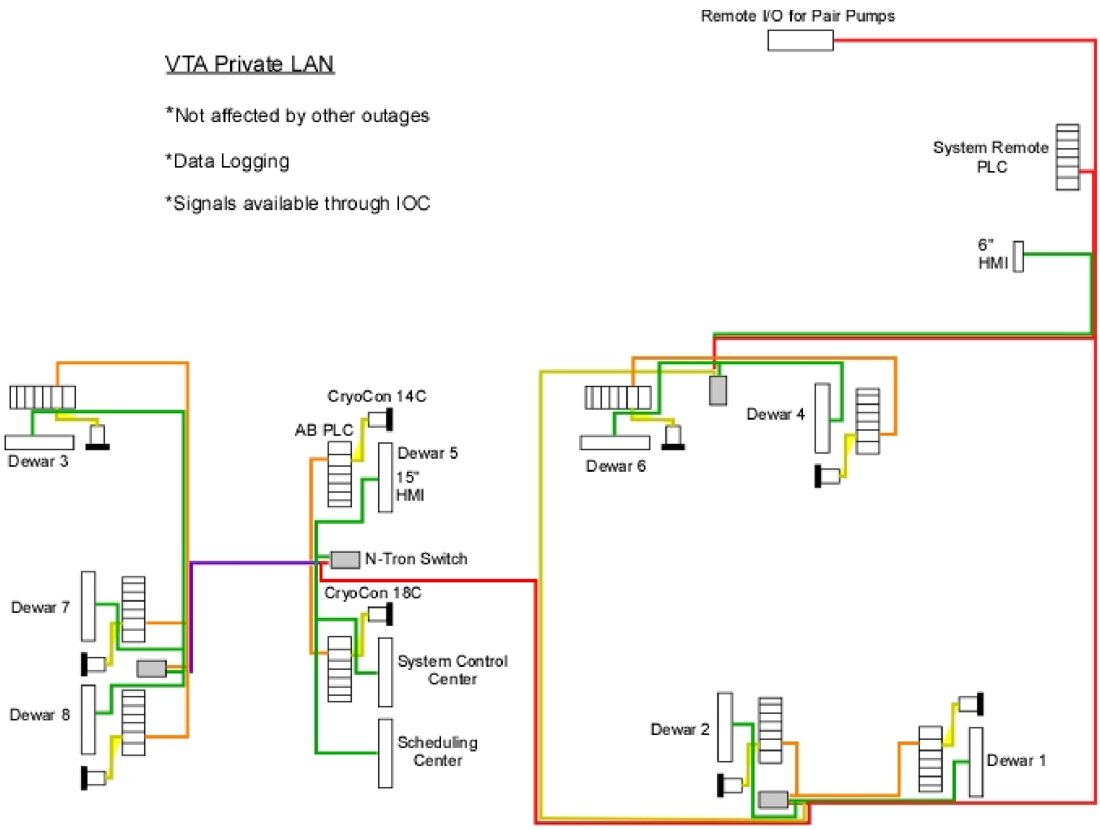

Figure 4: VTA controls, physical layout.

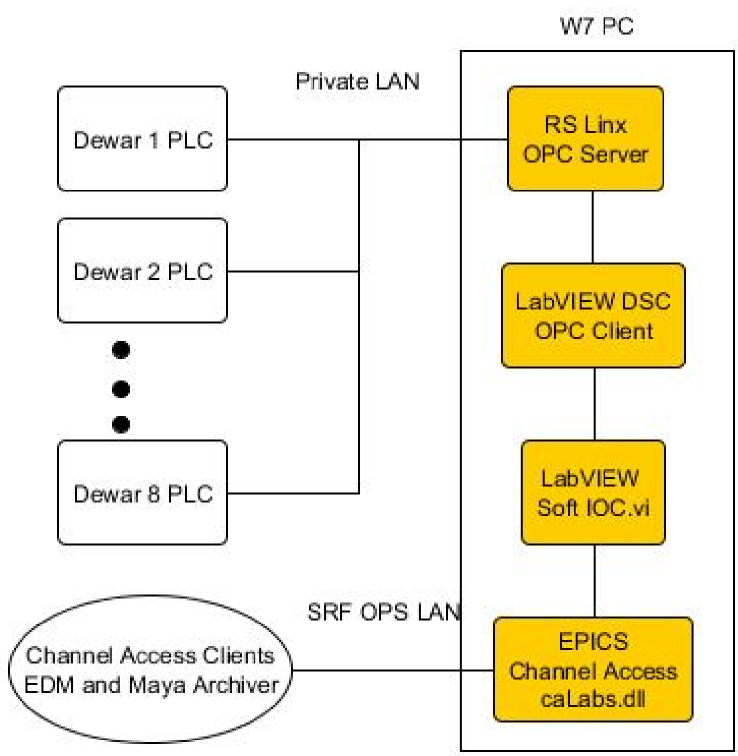

Figure 5: VTA controls, software layers.

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NETWORK ARCHITECTURE

The original control system relied heavily on serial and parallel communications protocols (e.g. RS-422, GPIB) that were dominant in the 1990's. The increasing prevalence of instruments and PLCs using TCP/IP led to choosing a LAN of this type as the communications backbone of the new control system.

To insure the reliability and security of this network, a segmented, virtual subnet was created without general connectivity outside the JLab firewall (see Fig. 4).

CONTROL SYSTEM SOFTWARE

The VTA is a user-operated facility, but all operations require special qualifications and training. The PLC user interface allows various levels of operational permissions via password-protected user login.

Interoperability between the VTA cryogenics controls and the CTF controls was important since we wanted to improve the integration between the two facilities. Because the CTF relies on EPICS, and since there are a wealth of familiar tools already available, we chose to use EPICS as the historical trending tool.

The VTA uses a LabVIEW EPICS caLab soft IOC in a Windows environment to monitor cryogenic data hosted by the PLCs. Several layers of software are used to connect the LabVIEW soft IOC to the PLC tags.

The PLCs are configured to communicate on a private LAN that is connected to one of two network cards on the Windows PC hosting the softIOC. RS Linx detects each of the PLCs on the private LAN. It hosts an OPC server that provides OPC access to the PLC tags. LabVIEW DSC is the OPC client that polls the RS Logix OPC Server for new PLC tag data. LabVIEW runs a softIOC that is the interface between OPC and EPICS Channel Access. LabVIEW reads the OPC tags and the softIOC broadcasts the data to channel access on the second network card connected to the SRF OPS LAN (see Fig. 5).

PROJECT STATUS

1. Dewars 1-6 have been converted to new PLC controls and have been returned to service.
2. Dewars 7, 8, and the System Rack are scheduled to be upgraded in the Fall of 2015.
3. Once all dewars have been upgraded, automation improvements will be implemented, prioritized to meet the needs of the user community. Integration with CTF controls will also begin.

CONCLUSION

The new control system installation is well underway and is already reaping benefits. Once completed in the Fall of 2015, the throughput and reliability will increase, operator staffing levels will decrease, cryogenic efficiency will improve, and safety will benefit. This unique facility will be ready to serve the SRF community for another 25 years.

REFERENCES

[1] Jlab.org website: https://srf.jlab.org/srf/ResourcesTab/vta.htm

[2] C. Reece et al. "A Closed Cycle Cryogenic System for Testing Superconducting RF Cavities," proceedings of 1991 PAC, pp. 2325–2327.