MODERNIZATION OF PLC-BASED CONTROL SYSTEMS AT SNS*

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Abstract

When the SNS site was built around 20 years ago, the Conventional Facilities (CF) control systems were designed using 2 communication protocols to allow programmable logic controllers (PLCs) to interface with motors, variable frequency drives (VFDs), and remote input and output (I/O) devices. The protocol chosen to control motors and VFDs is DeviceNet, a CANbus-based protocol developed by Allen-Bradley, a subsidiary of Rockwell Automation. The protocol chosen to communicate with remote I/O is ControlNet, another protocol developed by Allen-Bradley. Both of these protocols are obsolete and present reliability and maintainability issues, particularly DeviceNet. As the Control Systems Section at SNS is working to modernize control systems throughout the machine, a major goal for PLC-based systems is to remove the obsolete communication protocols in favor of standard, ubiquitous Ethernet. To this end, any new VFDs installed use Ethernet communication. Many VFDs are currently being replaced in the Central Utilities Building (CUB) and the Central Exhaust Facility (CEF) and are being removed from DeviceNet in favor of Ethernet communication. Planning is underway to retrofit Eaton Intelligent Technology motor control centers (MCCs) in the Target Building to remove particularly troublesome DeviceNet adaptors and replace them with Ethernet adaptors for each motor starter. The ControlNet network in the CUB has been demolished, with I/O drops integrated into a local Ethernet network, improving sustainability and maintainability.

BACKGROUND

The greatest vulnerabilities in Conventional Facilities (CF) control systems at Spallation Neutron Source (SNS) currently lie with the communication protocols in use. Both DeviceNet[1] and ControlNet[2] were part of the original designs and are obsolete. DeviceNet networks were installed to facilitate programmable logic controllers (PLCs) communicating with variable frequency drives (VFDs) and motor starters in CF control systems. DeviceNet has, however, proven itself to be unreliable, exhibiting issues that can often bring down large portions of the network or even the whole network. It is sensitive to network changes and physical connections are often broken over time, possibly due to heating and cooling cycles in motor control centers (MCCs). These issues often take more time to correct than other control system issues because of the caution and coordination needed to troubleshoot within live MCCs. ControlNet was implemented to allow PLCs to communicate with remote input and output (I/O) hardware. It is deterministic, meaning communication with devices happens at established times for established time intervals. This factors into scheduling the ControlNet network, but most of the work is taken care of by the software (RSNetworx for ControlNet). One disadvantage of ControlNet is that it is not ideal for future I/O additions, which are not always predictable. If any new I/O hardware is added to the network, the network must be rescheduled, which requires putting the PLC into program mode, stopping the process. While this may not endanger run time, some processors require great coordination before putting them in program mode, making this unideal. In addition to this, some of the ControlNet hardware used in CF control systems has been discontinued, while other critical hardware will also be discontinued in the near future. Because of the vulnerable state these protocols put control systems in, whether from a reliability or maintainability standpoint, the Controls Systems Section at SNS has been working toward replacing them with Ethernet/IP[3] (EIP). EIP is a superior communication protocol for use with Allen-Bradley PLCs and communicates via the Ethernet medium.

LOCAL ETHERNET NETWORKS

One step that has been crucial in the change to using EIP is setting up local Ethernet networks for each PLC that is modernized (Fig. 1). The local Ethernet network replaces the functionality of both DeviceNet and ControlNet networks simultaneously. Another benefit of setting up a local Ethernet network is to restrict access to each device or I/O drop to the PLC only. It also cuts down on unnecessary traffic on the Integrated Control System (ICS) network.

VFD REPLACEMENTS

A major ongoing project in the Central Utilities Building (CUB) at SNS is the replacement of 16 VFDs that support Chilled Water and Tower Water supplies across the site. These VFDs run pumps for these systems as well as fans for cooling towers. An effort to replace these VFDs due to obsolescence has provided the opportunity to remove them from the DeviceNet network in the CUB and add the new VFDs to the local Ethernet network. The existing VFDs were ABB drives, while the replacements are Danfoss (Fig. 2).

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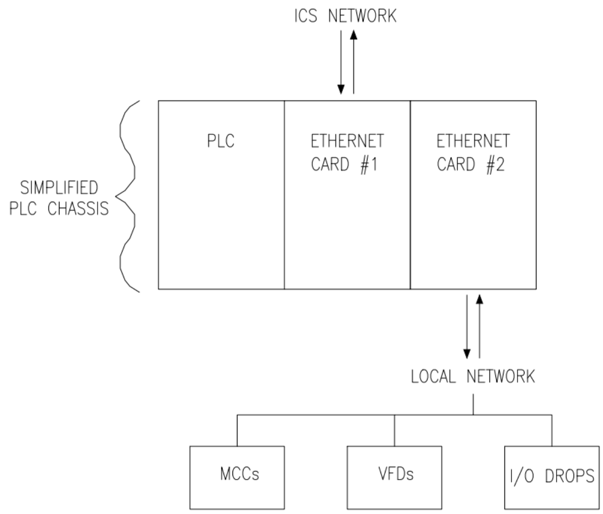

Figure 1: Simplified network diagram.

Figure 2: Old VFD (left) and new VFD (right).

Removing VFDs from the DeviceNet network produced mixed results. The expected response is to have an "E78" error show up on the DeviceNet scanner, which indicates a physical loss of connection to a device in most cases and only affects that one device. However, some cases showed that simply removing a VFD's physical connections (to the network) can upset the whole network to the point of requiring a network reboot.

Methods of EIP Communication

The standard configuration for new VFD installation consists of using digital and analog signals for control, while using EIP for non-critical data. The standard control signals are speed command, speed feedback, run command, run status, and fault status. Up until recently, Ethernet communication to VFDs has taken place via EIP messaging using Studio 5000's[4] "MSG" instruction. This was how Danfoss VFDs were originally integrated into CF control systems. This configuration became standard for new installations as the routine for processing data could be exported and imported easily enough. Indeed, it is satisfactory for most implementations in CF control systems at SNS. However, the inefficiency of EIP messaging began to show itself when replacing the number of VFDs at the CUB. Testing showed it would often take 10-15 seconds for the PLC to retrieve 1 set of data from a given VFD, which is terribly slow for EIP. Efforts were made to increase the efficiency of these Ethernet communications, which led to the discovery of the generic Danfoss VFD Electronic Data Sheet (EDS) file. The EDS file describes the readable and writable parameters of the VFD to the PLC and allows a user to add each VFD to the PLC's I/O configuration as an EIP device. After this, a tag structure is automatically set up showing direct I/O to and from the VFD (Fig. 3).

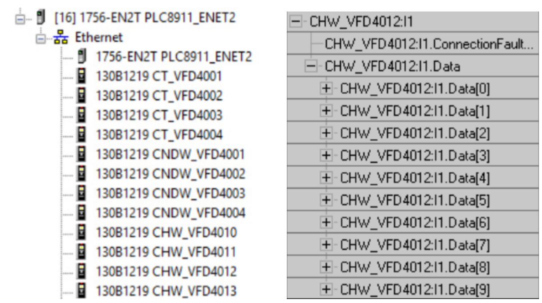

Figure 3: EIP devices added to PLC I/O configuration (left) and tag structure set up from EDS file (right).

The difference this change in Ethernet communication made was extraordinary. Scan times for each VFD dropped below 1 second, in keeping with I/O drops (requested packet interval is 20ms, but the PLC program updates the display closer to 1 second). Part of the reason this change was so effective is that using the EDS file allows the PLC to send 1 request for all data to the VFD, whereas EIP messaging requires separate requests for each parameter. This is because the messages access various data registers, but the EDS file method only reads from 1 location.

Central Exhaust Facility (CEF) VFDs

Much like the case with the CUB, most of the CEF VFDs (8 of 10) were obsolete and in need of replacement (Fig. 4).

Figure 4: Old CEF VFD configuration.

This also presented the opportunity to rid the CEF PLC of its DeviceNet network in favor of Ethernet. In light of lessons learned from the CUB replacements, the CEF replacements were mostly straightforward. It turned out, though, that there was not enough room in the existing underground conduits to run 5 signal cables and 1 Cat6 cable for each VFD. The decision was made, therefore, to retrieve the "run status" and "fault status" signals via the Ethernet connection in order to reduce the number of cables in each conduit. While these 2 signals provide valuable information, they were considered the least critical of the 5 aforementioned signals because in the event of losing the Ethernet connection, the CEF systems can still function. This is because they use pressure differential switches both for proving fan statuses and flagging fan failures. Figure 5 shows the result of the replacement project, with the new VFDs noticeably more compact.

Figure 5: New CEF VFD configuration.

CONTROLNET CONVERSION

Transitioning the CUB's ControlNet remote I/O to EIP was made simple by the PLC manufacturer, Allen-Bradley. Both the ControlNet and EIP adaptors have the same footprint and could be physically exchanged in under a minute (Fig. 6).

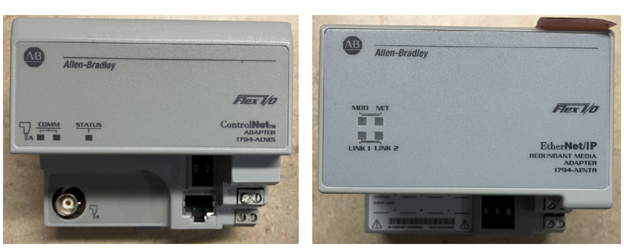

Figure 6: Allen-Bradley Flex IO series communication adaptors.

All that was required in the PLC program was to move all modules in the I/O configuration from the ControlNet network to the Ethernet network. A simple copy and paste of each module also duplicated the I/O tags and their descriptions, making for an easy transition (Fig. 7). Due to the nature of these EIP adaptors replacing existing hardware, however, all these changes needed to be done offline, requiring coordination with operations.

Figure 7: Remote I/O migration.

PLANS FOR MCCS

The highest priority in future conversions to EIP is retrofitting the Target building MCCs (Fig. 8). These MCCs (Eaton/Cutler-Hammer Intelligent Technology models) often feature a DeviceNet adaptor that acts as the main point of contact for the MCC, which then communicates via a proprietary protocol with each bucket individually. This adaptor adds another layer of complexity to the DeviceNet network and has its own troubleshooting guide to help resolve the various issues it can exhibit.

Figure 8: Target building MCC.

As the Target building has easily the least reliable of all CF DeviceNet networks, plans to retrofit these MCCs have been established. Current plans include running fiber optic cable to each MCC from the associated PLC enclosure and retrofitting one bucket in each MCC to have a 480VAC/24VDC power supply, a fiber/Ethernet converter, and an unmanaged industrial Ethernet switch. Each bucket in the MCC that has a motor starter will be fully retrofitted and will include an Eaton C441[5] Ethernet module for communication. An EDS file is available for the C441 that will facilitate easy integration into the existing control system.

CONCLUSION

Plans to replace VFDs and modernize the controls for them have been successfully carried out. While quantitative data is not yet available, demolishing the DeviceNet controls in favor of analog, digital, and EIP suggests that the reliability of CUB and CEF systems has been improved. Replacing the remote I/O ControlNet adaptors in the CUB with EIP compatible adaptors was a great step toward increasing the maintainability of this control system while also freeing up spares for possible ControlNet adaptor failures on other systems. Plans for DeviceNet conversions to EIP are being fleshed out for the Target CF systems, while those participating remain optimistic that the upgrades will greatly improve the reliability of these control systems.

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