Solving the Store/Forward Backup Datalogging Requirement: DNP3 Protocol

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One of the most challenging aspects of SCADA (supervisory control and data acquisitions) systems is how to implement robust datalogging – that is datalogging that will not "lose data" during a SCADA communications outage. Robust datalogging is an important feature, particularly for water treatment facilities that must log chlorine residuals every five minutes, and keep track of daily flow totals.

Why Robust Datalogging is Difficult

Traditionally, most SCADA systems work by logging data at centrally located servers, which receive real-time data feeds from field PLCs – hence, any interruption to the SCADA wide area network can result in lost data. Trying to decentralize datalogging and/or add redundant datalogging has historically been difficult. Many SCADA packages and related SCADA communications protocols are simply not designed to do anything other transmitting real-time data and then log it on a centralized server. Past approaches to get around this limitation have been difficult to implement and expensive. Common workarounds include: deploying additional SCADA servers at remote facilities with the additional associated hardware/licensing costs, custom scripting in PLCs/servers that has to be programmed/maintained, implementing proprietary hardware/software solutions, or using standalone dataloggers from which data must be manually pulled by hand. All of these workarounds are generally difficult, expensive, and/or subject the utility to "vendor lock-in."

This article discusses how the DNP3 (Distributed Network Protocol Version 3.0) communications protocol, which was developed by the electric power industry for electrical substation communications, can be used to quickly/easily implement store/forward datalogging in a SCADA system. In a store/forward datalogging scheme, the field PLC will locally record/timestamp data records and store them during a communications outage, and then forward the data records when communications are restored.

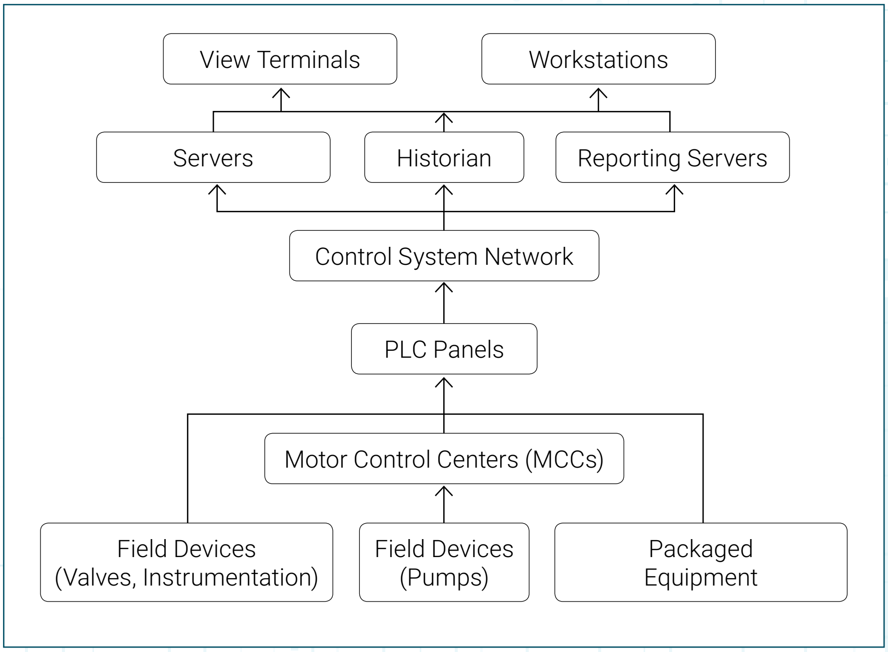
SCADA System Primer

In modern water utilities, SCADA systems play a central role within operations. SCADA systems enable operations staff to monitor and interact with process equipment, run automatic control programs, and log critical compliance data. For example, it is now very common for pumping stations and treatment plants to run under fully-automatic SCADA control, with the operators making periodic setpoint adjustments rather than the traditional role of turning valves or starting/stopping pumps.

SCADA systems are complex, with many layers of equipment, software, and programming contributing to their overall operation. In a typical SCADA system, these layers include: field devices (pumps, valves, and instrumentation), field wiring, controllers (PLC, PAC, RTU, etc.), a control system network, servers, view terminals/workstations, process historian, and reporting servers. All of these layers must work together, on a 24/7 basis, to enable a SCADA system to function correctly. These layers are shown in **Figure 1**.

However, no technology is perfect and failures are possible in any SCADA system, no matter the quality of the components used. Thus, it is important that SCADA systems are designed to have built-in redundancy so that a component or communications failure does not take the system offline or interrupt the logging of critical compliance data.

Figure 1. Layers in a typical SCADA System.



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Importance of Datalogging

The datalogging of compliance data by SCADA systems is particularly important for water utilities. For example, in Ontario Canada, Regulation 170 of the Safe Drinking Water Act requires that chlorine residual concentrations for drinking water be logged every five minutes at water treatment facilities. It is through the logging of chlorine residuals (expressed in mg/L) that the effective primary and secondary disinfection of water can be proven to be within regulatory compliance. Thus, to prove regulatory compliance, a SCADA system's datalogging feature must always be functioning.

Backup Data Logging with DNP3

Guelph Water, like most utilities, has had a SCADA system for many years. In 2017, a risk assessment by the SCADA department identified that the SCADA process historian and individual site PLCs were potential single points of failure. The process historian is the server that records process data, including regulatory compliance data, for the SCADA system. Thus, in 2017-2018, Guelph Water undertook a project to add a backup data-logging system to its SCADA system using the DNP3 protocol. DNP3 stands for Distributed Network Protocol Version 3.

Designed to supplement the primary SCADA system, the DNP3 backup data logging solution consists of a backup historian and DNP3-enabled datalogger PLCs (programmable logic controllers) that use the DNP3 protocol to push critical process data up to the backup historian. So, if there was ever an outage in the main SCADA system, the fully independent DNP3 data logging system will continue logging data to its centralized backup historian.

The DNP3 protocol was chosen for several reasons. These included automatic timestamping of process data at the PLC, built-in store/forward data-logging, automatic time synchronization, and minimal configuration needed to setup data points. Since DNP3 is built on the concept of time-stamped events (stored process value readings that each have a date/time stamp associated with them), DNP3 can easily tolerate communication outages unlike other real-time SCADA protocols such as MODBUS, ProfiNet, DeviceNet, ControlNet, CIP, Ethernet/IP, and BSAP. Unlike other real-time protocols, in the event of a communications disruption, DNP3 data events are simply stored in a time-stamped memory buffer and then forwarded when communications resume.

The DNP3 protocol originated from the electric power industry where it is used for communications between electrical substations. DNP3 was first developed in 1990 by Westronic Inc. (now GE Harris) and was published as an open standard in 1993. Since then, it has become widely used for electrical substations across North America, along with its successor protocol IEC-61850. In 2000, DNP3 was standardized as IEEE communications standard 1379-2000 and uses IEC-62351-5 for authentication.

DNP3 Primer

DNP3 is a set of conventions by which devices can talk with each other, typically within automatic control systems. Developed primarily for SCADA systems with remote sites that communicate back to a central computer, DNP3 is an ideal protocol for SCADA data logging.

DNP3 protocol has the flexibility to log data on set intervals (say every five minutes) or to only log values when a number changes more than a predetermined threshold amount. In the implementation at Guelph Water, we only used the feature of logging data on set time intervals. The fixed time interval was chosen so that data logged could be used to meet the five-minute regulatory logging interval requirement.

The major strength of DNP3 is its ability to do automatic/store forward datalogging as part of the protocol – with no special programming required. In other non-DNP3 systems, complex scripting and custom data buffers are often needed on both the PLC and Historian sides to implement store/forward datalogging. DNP3 avoids all of this complexity. **As part of the DNP3 protocol, the store/forward datalogging feature is automatically included as part of the protocol.**

DNP3 is also versatile in the numerous ways that it can communicate, including Ethernet, serial wire connections, fibre optic systems, as well as cellular and radio-based systems. DNP3 protocol also can be setup to communicate to multiple master stations. DNP3 has four levels of implementation, from the simplest (Level 0) to the most feature-rich (Level 4). For example, the automatic store and forward data-logging is part of the DNP3 Level 2 and above feature sets.

DNP3 is not the first technology to implement "part-of-the-protocol" automatic store and forward data-logging, but it is unique in that it is an established and publicly-available published standard. Thus, DNP3, due to its dominance and availability in the electric power industry, has wide range of controllers and SCADA software packages available that support it. Many of the other non-DNP3 store/forward data-logger technologies in the market place are vendor-specific, proprietary, and/or require extensive custom scripting to implement.

DNP3 Data Logging System Components

The DNP3 data-logging system at Guelph Water was designed with the goal of avoiding single points of failure. Thus, to gather data from the field, the existing SCADA PLCs were not used (as the existing PLCs could be considered a single point of failure). Instead, the DNP3 system has its own dedicated data-logger PLCs that collect process data by being "wired-into-the-loop" of key analog 4-20mA signals. These dedicated data-logger PLCs natively support DNP3 protocol, and then push data up to the DNP3-enabled backup historian.

For the DNP3 data-logger PLCs, several hardware options were considered. For Guelph Water, the Allen-Bradley Micrologix 1400 PLC was selected for its low cost and the ability to program it with existing programming software that Guelph Water already had licenses for.

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As a key feature, the Micrologix 1400 natively supports the DNP3 protocol through its Ethernet port, including DNP3's automatic store/forward data-logging feature. The Micrologix 1400 also has a large enough onboard memory buffer to store at least a week of logged data in its store/forward buffer. With an appropriately-sized buffer, DNP3's store/forward feature works automatically with no operator or programmer intervention required.

The Micrologix 1400 also offers an inexpensive four-channel isolated analog input card, which can be used to read existing 4-20mA signals by "wiring-into-the-loop." To keep costs down, only signals of key regulatory importance at well sites are logged by Guelph Water's DNP3 system: well flow rate, point-of-entry chlorine residual, point-of-entry flow rate, and contact chamber level. How the 4-20mA signals are read into the system is by "wiring-into-the-loop" as shown in **Figure 2**.

Selecting a backup historian (and associated communications driver) that supports the full DNP3 store/forward data-logging feature proved to be challenging, as there were many products in the market place that only supported DNP3 Level 0, but not the required DNP3 Level 2. (DNP3 Level 0 does not include the store/forward data-logging feature.) To support DNP3, several of the software packages also required various add-on modules, which were either costly or difficult to configure. In the end, Schneider Electric's ClearSCADA software was selected, as it has both native DNP3 store/forward data-logging support and a built-in process historian. Guelph Water also had previous experience using ClearSCADA for its district metered area (DMA) flowmeters, so there was familiarity with the software.

For communications between the Micrologix 1400 PLCs and the ClearSCADA software, the existing Ethernet-based Guelph Water SCADA wide-area network was used. Each data-logging PLC, as well as the ClearSCADA server, was assigned a unique static IP and was then configured to communicate with the server directly using the DNP3 protocol on Ethernet port 20000.

Figure 2. Wiring a Datalogger "into the loop" on 4-20mA analog signal from a flowmeter.

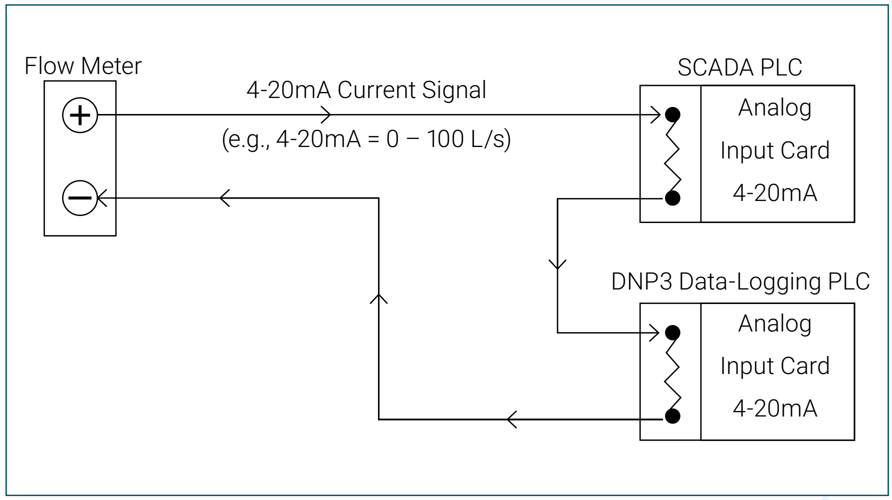


Figure 3. Enabling DNP3 Communications in Micrologix 1400 PLC.

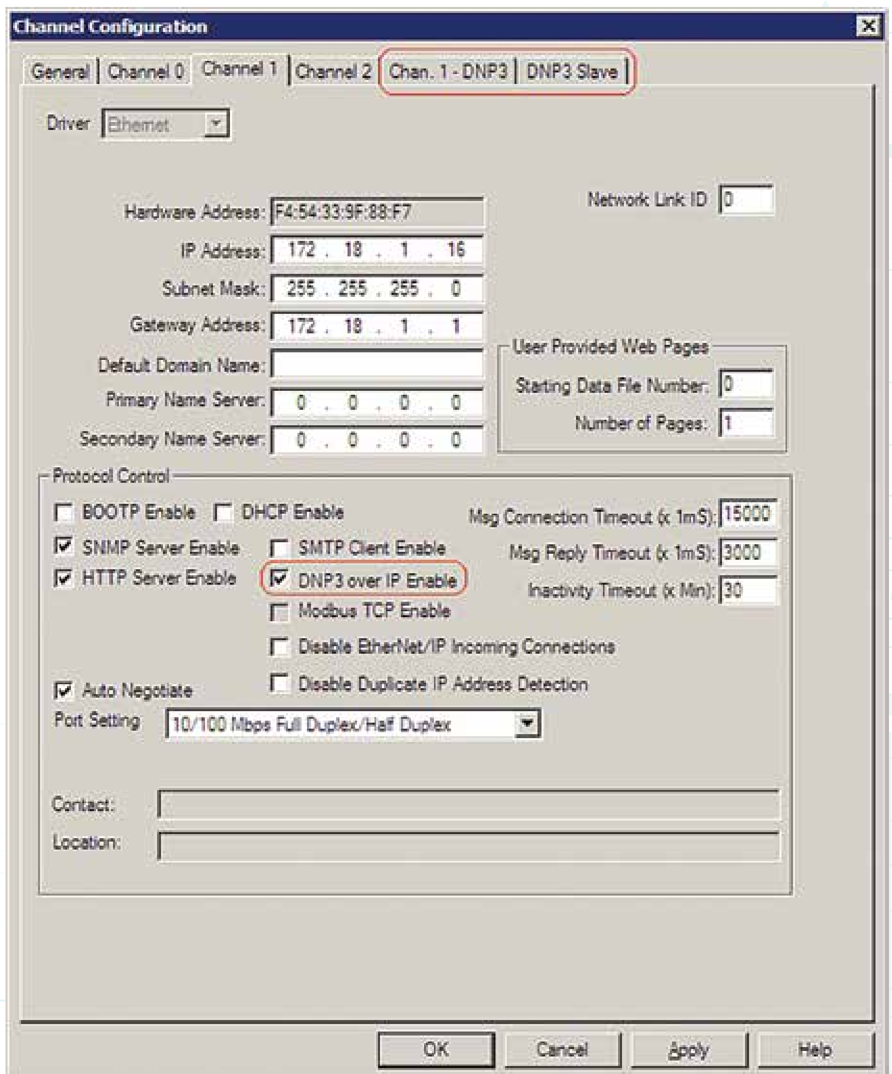


Figure 4. Mapping Memory registers to the DNP3 data points on Micrologix 1400 PLC.

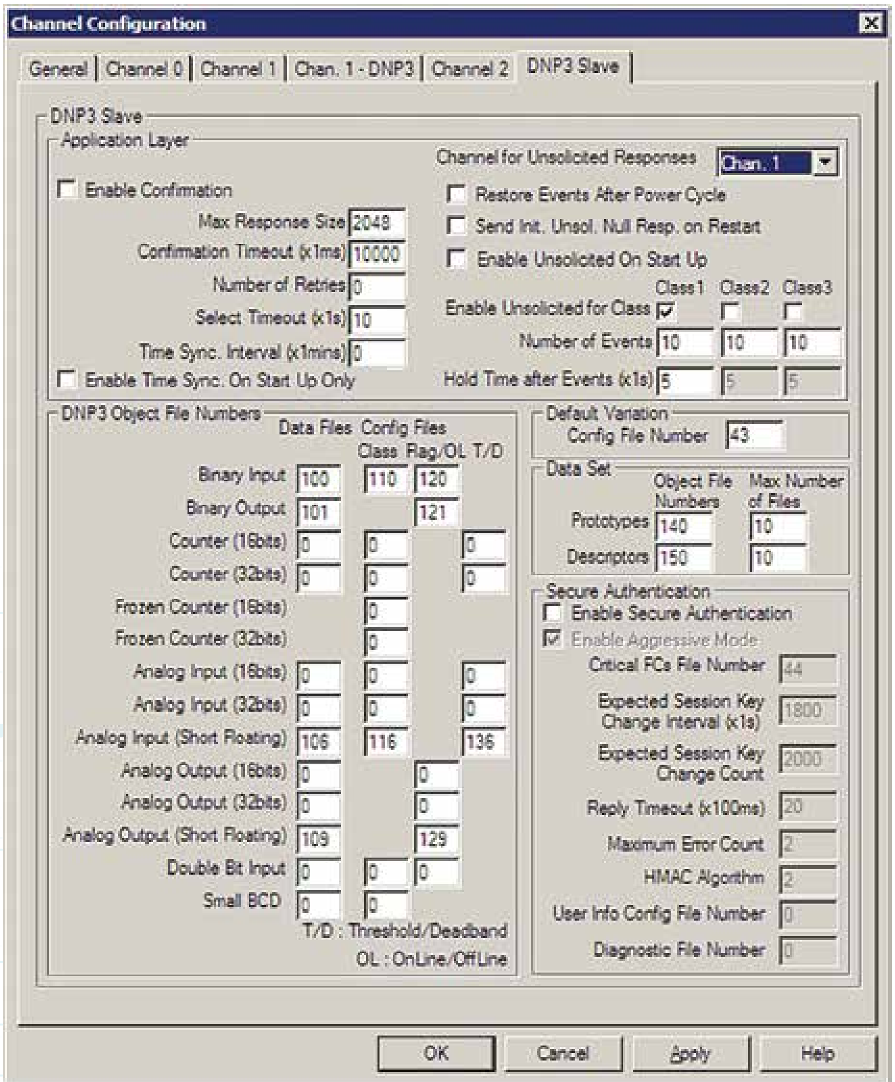
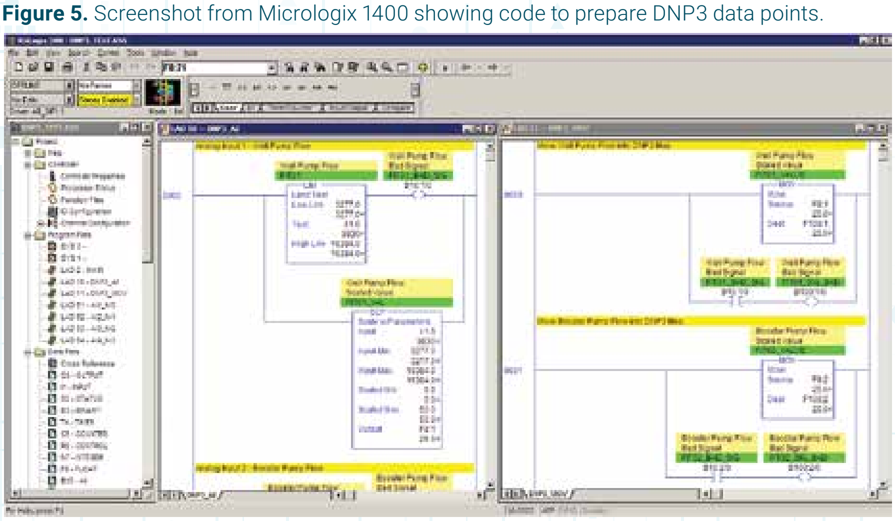


Figure 5. Screenshot from Micrologix 1400 showing code to prepare DNP3 data points.



Micrologix 1400 Configuration

Setting up the Micrologix 1400 to communicate via DNP3 required some special configuration that was unique to this specific PLC. From the RSLogix 500 programing software, this was accomplished by using two configuration windows. The first step was to Enable DNP3 over Ethernet communications (**Figure 3**), after which the two tabs for DNP3 communications appeared "Chan.1 – DNP3" after and "DNP3 Slave" before. The "DNP3 Slave" tab was used to setup the DNP3 data points using the Micrologix 1400 memory registers. The "Chan. 1 - DNP3" tab is only used for DNP3 serial-to-Ethernet pass-through applications.

The "DNP3 Slave" tab is used to configure how the externally facing DNP3 data registers are mapped to the Micrologix 1400's internal registers. Some internal Micrologix 1400 registers are used to hold data, while others within the PLC hold further DNP3 configuration details. (**Figure 4**). A thorough understanding of how the DNP3 protocol works was needed to configure this tab. Fortunately, Rockwell Automation provided an extensive instructional PowerPoint presentation. We found the Micrologix 1400 manual to also be a good resource. The actual setup took about 15 minutes once the correct configuration values were determined. For Guelph Water, the only DNP3 features we used were store/forward data-logging and a single DNP3 communications class (Class 1) to set the logging interval; the logging interval is handled by the DNP3 server's configuration.

The native memory model of the Micrologix 1400 consists of numeric data files that each consist of 1 to 255 elements in an array. The data files themselves are numbered from 3 to 255, and each data file can be defined as one of the native "SLC500" data types, namely Bit, Counter, Integer, Float, or other types.

The DNP3 native datatypes are based on arrays of object groups, which are, in order: Binary Input, Binary Output, Counter (16 bits), Counter (32 bits), Frozen Counter (16 bits), Frozen Counter (32 bits), Analog Input (16 bits), Analog Input (32 bits), Analog Input (Short Floating), etc.

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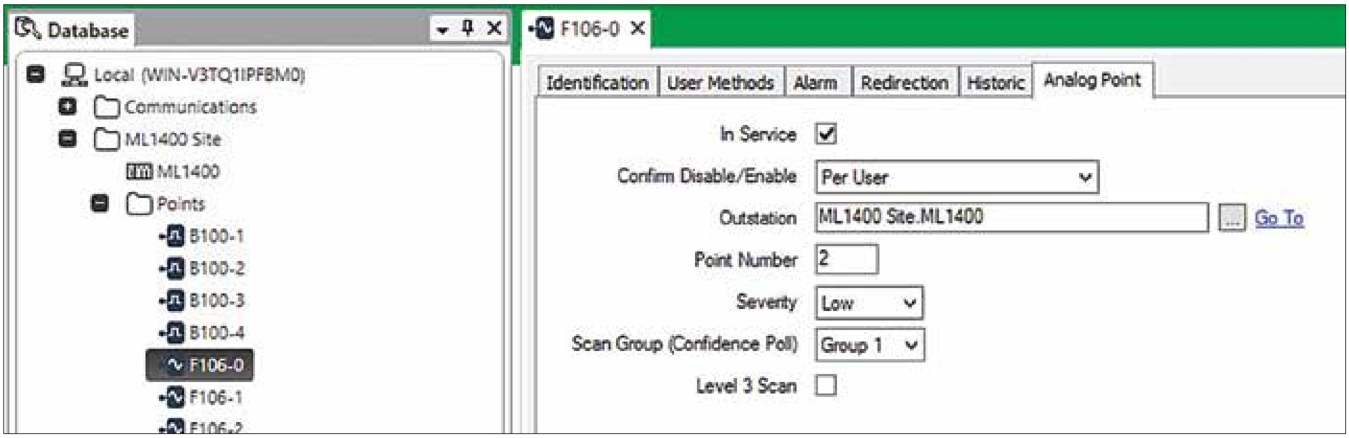
Figure 6. ClearSCADA configuration for DNP3 communications to Micrologix 1400s.



For our application, the Micrologix 1400 was set up with data file F106 (with 20 elements) to map to the DNP3 "Analog Input (Short Floating)" registers (on indices 0-19) for our process values. See **Figure 4** for how the mapping was done.

Within the Micrologix 1400 itself, a subroutine was added to scale the PLC's raw 4-20mA inputs to Engineering Units (e.g., 4-20mA = 0-100 L/s) and then another subroutine was added to copy the scaled engineering value to the appropriate DNP3 register in F106. Similar code was put in place to detect signal failures and map these "error bits" to the DNP3 "Binary Input" registers. Sample code from the Micrologix 1400 can be seen in **Figure 5**.

Lastly each Micrologix 1400 was assigned a static IP address, so the ClearSCADA server would know where to find it on the SCADA network.

ClearSCADA Configuration

Configuring the ClearSCADA server was straight-forward. Within the ClearSCADA interface, a series of DNP3 outstation objects were added to talk to each of the Micrologix 1400s. Within each DNP3 outstation object, a grouping of DNP3 "Analog Input (Short Floating)" objects were then added – one for each DNP3 address configured on that particular Micrologix 1400. DNP3 "Binary Input" objects were then added for the binary points as defined on each of the PLCs. A screenshot of the ClearSCADA configuration can be seen in **Figure 6**.

Putting it all together

Rolling out the DNP3-based data-logging system is taking place in several stages. First a bench-test was done to ensure the ClearSCADA software and Micrologix 1400 would communicate with each other. ClearSCADA was installed onto a Virtual Machine running on a laptop and it was tested with a single physical Micrologix 1400, running on a test network.

Next a Phase 1 test was started where Micrologix 1400s were installed at five sites and a ClearSCADA virtual machine was installed on a production SCADA server.

After the Phase 1 test is completed, the system will be rolled out to the remaining 30 facilities at Guelph Water. In each case, the Micrologix 1400 will be installed into the existing PLC panel where it can be powered from the existing UPS (uninterruptable power supply) and spliced into the existing 4-20mA analog signals.

Making the Backup Datalogger Data Accessible

In the past, the main issue with most backup data-logger systems has been how to get access to the data. The new DNP3-based system at Guelph Water has been specifically designed so the backup data is accessible at all times by operators and compliance staff. All data gathered by the DNP3 system is stored on the centralized ClearSCADA backup historian. This in turn is accessible via the web-based e.RIS reporting software that Guelph Water uses. Inside the e.RIS reporting software, the ClearSCADA backup historian is configured as a selectable data source that can be queried just like the SCADA system's main process historian. Gone are the days when someone has to go to a data-logger to manually extract data!

Summary

By using the DNP3 protocol to implement a backup data-logging system, Guelph Water is able to enjoy the benefits of using a publicly-available standardized communications protocol that natively supports store/forward data-logging. By utilizing a technology that has a strong track record from the electric power industry, Guelph Water has been able to implement a reliable and cost-effective solution that enhances the robustness of its overall SCADA system for both operations and compliance.

References:

DNP3 Protocol Association website: *www.dnp3.org*

DNP3 Q&A with Schneider Electric. *http://www.remotemagazine.com/main/articles/dnp3-qa-with-schneider-electric/* Remote Magazine. September 16, 2013.

Configuring Ethernet DNP3 Slave on the Micrologix 1400. PowerPoint slide deck. Mark Tabler. Rockwell Automation.

User Manual: Micrologix 1400 Programmable controllers. March 2017. Allen-Bradley. Rockwell Automation.

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