SCADA SYSTEM MAINTENANCE: AN OFTEN OVERLOOKED NECESSITY

Kyle E. Feist[1]
Dr. Charles Burt[2]

ABSTRACT

The design and implementation of a Supervisory Control and Data Acquisition (SCADA) system is typically undertaken by expert engineers and integration contractors. In order to provide a robust and reliable SCADA system, good design and installation practices are required. Preserving the initial SCADA system reliability requires good maintenance. Unfortunately, SCADA maintenance is often overlooked or underestimated.

There are two potential providers for SCADA maintenance activities. Some SCADA maintenance activities are best provided by the developer or installer of the SCADA system, before closing out a project contract. Other SCADA maintenance requirements are best provided by the irrigation district or SCADA system owner.

Because SCADA systems are typically custom assemblies of hardware and software, each one is unique. However, there exists an almost universal set of fundamental maintenance requirements that is not always a priority during the SCADA system installation and commissioning phases.

When the most basic SCADA maintenance requirements are not possessed, there are two possible results: SCADA system performance deteriorates, and long-term maintenance becomes overly expensive. This paper introduces a set of fundamental items that are necessary for long-term SCADA system maintenance, in addition to the most basic necessity: an adequate maintenance budget.

INTRODUCTION

Irrigation districts (including water user associations, water districts, private canal companies, etc.) are established to provide service to farmers into the foreseeable future. Districts primarily convey irrigation water via extensive, district-owned networks of physical infrastructure. Well-managed districts tend to keep up with the maintenance demands of physical infrastructure because:

1. Deferring maintenance can result in obvious consequences and negatively impact the level of service provided by the district. Examples include:
    a. inability to deliver downstream demands due to failed pumps/gates or ruptured pipelines
    b. reduced canal flow rate capacities
    c. increased travel time on canal roads
    d. excessive weeds and canal debris

[1] Senior Engineer, Irrigation Training & Research Center (ITRC), California Polytechnic State University (Cal Poly), San Luis Obispo, CA. USA. 93407-0730. kfeist@calpoly.edu
[2] Chairman, Cal Poly ITRC. cburt@calpoly.edu

2. Most tasks and responsibilities are well-understood and achievable.
3. There is sufficient in-house labor. In fact for many districts, staff members serve dual roles: operations staff during the irrigation season and maintenance staff during the off-season.

In general, districts have also been successful at maintaining good records and documentation of physical infrastructure. For example, archiving blueprints, property titles, and easement information is intuitive for most district administrators and engineers. However, things are rapidly changing. Districts of all sizes are accelerating the implementation new technologies to meet internal and external pressures.

One example is a Supervisory Control and Data Acquisition (SCADA) system. Implementing a SCADA system involves the installation of new physical and digital infrastructure. This new "technological" infrastructure also requires specialized skills and knowledge for excellent maintenance and record-keeping. The intent of this paper is to provide readers with an outline of key SCADA-related maintenance and record-keeping items.

SCADA MAINTENANCE PRE-REQUISITES

There are multiple SCADA maintenance prerequisites, or items that are considered absolute minimum requirements, for long-term SCADA system success.

Good Initial Design

With the following considerations, a good initial design can reduce the cost and overall burden for long-term SCADA system maintenance:

1. SCADA systems are composed of electronic components, which will ultimately fail, and sometimes fail unexpectedly. As such:
    a. Special attention placed on accessibility and maintainability for conduit and enclosure details can make the replacement of failed components easier.
    b. Redundancy of critical sensors and other items reduces system downtime.
    c. Special sensor installation details can reduce the negative impacts of heat and moisture, such as sensor drift and early failure.
    d. The appropriate implementation of diagnostic data and alarming can accelerate the troubleshooting process, without overtaxing operators with information and notifications.
2. Selecting hardened, industrial components that are replaceable with equivalent off-the-shelf products reduces frustration and long-term costs. It is always possible to lower the cost of SCADA projects by substituting in less expensive components. However, considering that less expensive components typically have shorter life spans, it is important to factor in the total cost of early replacement when selecting components. For example, in addition to the purchase price of the component, plus tax and shipping, other SCADA replacement costs include diagnosis (failures are not always self-evident), physical replacement, travel time and vehicle mileage, configuration, calibration, documentation and commissioning.

Adequate Maintenance Budget

Without sufficient budget, maintenance cannot be completed.

Available, Skilled Labor

Most things with SCADA systems are not visually apparent or simple. Compared with typical maintenance activities and documentation items for physical infrastructure listed in the first section of this paper, SCADA maintenance responsibilities can be obscure because:

1. Few irrigation districts employ experienced SCADA technicians.
2. SCADA systems continue to increase in complexity as new features and conveniences are added.
3. Maintenance and troubleshooting tasks require new and unique skills that are not currently provided by traditional educational institutions. In fact, the authors are unaware of any high school, trade school or higher education system that maintains a formal program for SCADA-specific training. Furthermore, not only are trained SCADA technicians hard to find, but tailored training courses for capable employees are rare, with the exception of some manufacturer-specific training.

In practice, good irrigation district SCADA technicians have some combination of general familiarity or expertise in most of the following areas:

1. Electrical and electronic circuits
2. Instrumentation
3. Programmable logic controller (PLC) and interactive display programming
4. Basic open channel and pipe hydraulics
5. Centrifugal pumps and variable frequency drives
6. Radios
7. Computer networks and administration

As the list above shows, an ideal irrigation district SCADA technician would have a diverse set of relatively specialized technical knowledge and skills. With smaller SCADA systems, it can be difficult to justify hiring a dedicated SCADA technician because there is simply not enough work. Nevertheless, there are a variety of options for irrigation districts with smaller SCADA systems:

1. Contract out maintenance tasks to integrators
2. Hire a SCADA technician part-time in conjunction with other, nearby irrigation districts.
3. Hire or train a SCADA technician that performs other duties as well

Access to Spare Parts and Specialized Tools

Replacing failed SCADA components is required to keep the SCADA system operational. Furthermore, component replacement and system maintenance can require specialized tools. In many cases, SCADA replacement parts and specialized tools are not available through local vendors, which brings up the question of purchasing these items before they are needed (stocking parts and tools).

KEEPING SPARE PARTS

Single component failures can halt the functioning of all or part of the SCADA system, otherwise referred to as downtime. To reduce the duration of SCADA system downtime some districts decide to keep a stock of spare parts in storage, but many districts do not. The decision to keep a stock of spare parts depends on a number of variables including up-front stocking costs, the extend and criticality of the lost SCADA system functionality, the duration of downtime, potential early obsolescence of the component while in storage, and other factors.

A relatively basic method of estimating potential SCADA system downtime is presented in Equation 1.

$$\text{Potential downtime (hours)} = T_{notice} + T_{travel} + T_{identify} + T_{purchase} + T_{install} \quad (1)$$

Where,
T_{notice} = the time in hours to notice there is a problem/failure
T_{travel} = the travel time in hours to visit the site, sometimes requiring multiple trips
$T_{identify}$ = the time in hours required to troubleshoot the problem and identify the failed part
$T_{purchase}$ = the time in hours required to request a purchase and receive the part
$T_{install}$ = the time in hours required to install, calibrate/configure and commission the replacement part and revive the system

A potential downtime of three weeks is not unheard of. Furthermore, some districts have restrictive purchasing procedures that can delay the process further. It is recommended that readers use the equation informally to get a sense of, and prepare for, potential worst-case scenarios.

MINIMUM SCADA RECORD-KEEPING REQUIREMENTS

Proper SCADA-related record-keeping minimizes the cost of future SCADA system modifications, expansions, and some maintenance activities. Due to the complexity of modern SCADA systems, a complete set of minimum documentation items involves multiple hard/softcopy formats. Common documentation formats include:

- spreadsheets
- drawings and schematics
- executable programming/configuration software
- application files, developed/configured in the item above
- benchmarking records
- miscellaneous electronic and hardcopy files

The minimum SCADA documentation requirements are the same whether the work was completed by district personnel, consultant, or contractor. Typically documentation items are best created by the person or entity responsible for the particular item's implementation. In fact, reverse-engineering the details later on, by others, can be unjustifiably expensive or impossible, and should therefore be avoided. Furthermore, much of the documentation items are created by the developer, by default, to internally organize implementation work.

A detailed list of minimum SCADA maintenance documentation is provided in Table 1.

Table 1. Minimum documentation items for typical SCADA systems, not including software or application files

Description	Typical format	Minimum features	Other items that are convenient
Remote terminal unit (RTU) wiring diagram for all sites including radio repeaters	PDF drawing, or schematic	Individually labeled wire connections, internal and external panel layouts (with dimensions) and a bill of materials with makes, part numbers and quantities	
Tag list (for all project PLCs and dataloggers)	Spreadsheet	A database of individual programmable logic controller (PLC) tag names, with associated descriptions, units, tag addresses, and data formats	Additional details related to the configuration of communication protocols (e.g., Distributed Network Protocol (DNP) details) or details related to configuring the human-machine-interface
Radio network diagram (for all radio networks featuring repeaters, multiple radio types or elaborate routing schemes)	PDF drawing or schematic	A visual representation of the radio network topology	Labels showing the radio operating frequency or channel of each radio link
Networked hardware addressing database	Spreadsheet	A database of all Ethernet connected devices with associated Internet Protocol (IP) addresses, subnet masks, gateways and Media Access Control (MAC) addresses	Elaborate subnetting or Virtual Local Area Network (VLAN) descriptions
Base station networking diagram (for all base stations featuring more than two SCADA-related devices)	PDF drawing or schematic	A visual representation of all components and links within the private network and all public network connections. Labels should include all pertinent Open Systems Interconnection (OSI) Layer 1-3 information	Ethernet switch diagram, where ports are managed
Password list	Spreadsheet	A list of all passwords providing all levels of access, including administrative privileges to all systems with good descriptions	

A basic taglist example is provided in Table 2 for clarification. While critical for documentation purposes, taglists can also be used to quickly import tags into PLC programs.

Table 2. Example taglist excerpt for two internal PLC flow rate computations. In this example the tags are mapped to Distributed Network Protocol (DNP) points and Modbus registers. Note that the table also includes engineering units, expected value range and significant figures for display

<table>
<tr><th>Name</th><th>Data Type</th><th>DNP address</th><th>DNP Class</th><th>Variable Type</th><th>Modbus Address</th><th>Description</th><th>Unit</th><th>Range (Min)</th><th>Range (Max)</th></tr>
<tr><td>Q_FB</td><td rowspan="2">Short floating point</td><td>17</td><td rowspan="2">1</td><td rowspan="2">Real</td><td>40033</td><td>Flow rate over flashboard</td><td rowspan="2">CFS</td><td rowspan="2">0.0</td><td rowspan="2">60.0</td></tr>
<tr><td>Q _SPILL</td><td>19</td><td>40037</td><td>Total spill flow rate</td></tr>
</table>

Additional record requirements and other details for software-related SCADA components are listed in Table 3. The requirements are marked conservatively. In other words, sometimes the documentation is required, but there are always exceptions. When an exception exists for items marked as required ("Y"), districts should request a written justification from the developer, describing the exception.

Table 3. Additional minimum software-related requirements for particular types of SCADA system components.

<table>
<tr><th>SCADA Component</th><th>Manufacturer's Software*</th><th>Software License**</th><th>Application File†</th><th>User Name and Password‡</th></tr>
<tr><td>"Smart" sensors and instrumentation (ex. acoustic Doppler velocity meters)</td><td>Y[1]</td><td>N</td><td>Y</td><td>N</td></tr>
<tr><td>PLC or datalogger</td><td>Y[1]</td><td>Y</td><td>Y</td><td>Y</td></tr>
<tr><td>Field user interface/display</td><td>Y[1]</td><td>Y</td><td>Y</td><td>Y</td></tr>
<tr><td>Unmanaged Ethernet switch</td><td colspan="4">N[3]</td></tr>
<tr><td>Managed Ethernet switch</td><td>Y[1]</td><td>N</td><td>Y</td><td>Y</td></tr>
<tr><td>"Smart" electronic gate actuator</td><td>N[2]</td><td>N</td><td>N</td><td>N</td></tr>
<tr><td>Variable Frequency Drive (for pumps)</td><td>N[1]</td><td>N</td><td>Y</td><td>N</td></tr>
<tr><td>Radios</td><td>Y[1]</td><td>N</td><td>Y</td><td>Y</td></tr>
<tr><td>Office workstation</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td></tr>
<tr><td>Office server(s)</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td></tr>
<tr><td>Human Machine Interface (HMI) program polling remote sites for updated data and presenting that information to the user. Examples: ClearSCADA, FactoryTalk, etc.</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td></tr>
<tr><td>Office firewall</td><td>Y[1]</td><td>Y</td><td>Y</td><td>Y</td></tr>
</table>

* Typically requires manufacturer software, installed on personal computer or server to configure device
** Typically requires a software license, at additional cost, to fully utilize configuration software
† Configuration may be saved in an application file or text-based configuration list that can be archived on hard disk storage elsewhere for future use
‡ May require a password to view, modify or reuse application file
[1] Manufacturers are now integrating web servers in some of these devices, eliminating the need for a user to have software installed on laptops. Instead, the configuration interface is accessed via a standard web browser when networked to the device.
[2] Configuration is typically completed in the field using local buttons, remotes and/or a display integrated into the device
[3] No configuration is typically necessary. Things just "work"

Additional Recommendations

There are other documentation items that will make future maintenance more efficient, but are either not absolutely required, or relatively easy to reverse engineer or look up after the fact. Examples of such records include:

- A list of Federal Communications Commission (FCC) radio licenses and renewal dates. Searching for existing telemetry radio licenses can be completed using the FCC Universal Licensing System Search Tool found at: http://wireless2.fcc.gov/UlsApp/UlsSearch/searchLicense.jsp
- Software and third-party service/license and account information, including a summary of recurring fees and payment information
- A list and description of all remote access connections, including security features
- A complete list of software used for the project, the function and installation location of each (including detailed virtual machine configurations and capacity allocations)
- Radio field test results and benchmarks
- Interconnection wiring diagrams between an RTU and other site components

It is also recommended to keep multiple backup copies of the documentation in different, protected locations.

CONCLUSION

A number of SCADA system maintenance prerequisites are critical for long-term success, the most important of which are a good initial design/installation, and adequate budget for future operations and maintenance. Adequate documentation is also necessary for future SCADA system maintenance, expansion and modifications.

For a variety of reasons, ensuring good documentation is collected and archived can be difficult, regardless if the work was contracted out or performed in-house. The first step towards improving district documentation practices for SCADA systems is knowing what documentation is important.

Once documentation requirements are known, the next step is incorporating them into any SCADA project, for both in-house and contracted work. Lastly, the documentation must be collected and verified, preferably from the person or entity doing the work. Keeping backup copies of all documentation is also a good idea.