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U.S. Committee on Irrigation and Drainage

The U.S. Society for Irrigation and Drainage Professionals

Letter to Membership: We Need Your Help!

Dear Membership,

USCID has experienced many changes in the last few years, with COVID, the retirement of Larry Stephens, and challenges getting new leadership in place.

We are excited now to be moving forward with our new Executive Director, Jane Townsend, with Ag Association Management Services, Inc. Jane can be reached here: jane@agamsi.com.

We had to delay our Fall Conference that was scheduled for 2022, due to lower than expected registration. This was partly due to our technical difficulties, which we are now diligently addressing. We want to assure you that the USCID organization is here to stay.

We hope to see you at the next conference that we have scheduled to take place in Fort Collins on October 17-20, 2023. Please mark your calendars! Those who submitted papers and abstracts for the Fall 2022 conference will automatically have a spot to present their work at this rescheduled event.

USCID will be launching a massive fundraising campaign to raise money to pay our ICID membership. We have been hit financially by the delay of the conference (our biggest fundraiser), some COVID-induced membership "retirements," and inconsistencies and technical difficulties

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Details on page 2!

Winter 2023
Issue No. 1001

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processing membership renewals. As we work to bring our membership rolls back up to date, please consider making an extra donation to USCID to help us raise funds to support our continued mission!

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Obtaining Title to Federal Water Projects & Gaining International Recognition of Water Projects

Speaker: Franklin E. Dimick, Dimick Water Resources Engineering

Apr 12, 2023 11:00 AM Pacific Time (US and Canada) on Zoom

Participants will also receive an update from USCID and see how the USA can gain international recognition on water projects.

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SCADA Preventative Maintenance: Reducing the Potential of Unexpected Failures

by Kyle Feist, Zach Markow, and Charles M. Burt, Cal Poly Irrigation Training & Research Center

Abstract

Irrigation district infrastructure utilizing Supervisory Control and Data Acquisition (SCADA) systems can perform a critical service to irrigators, but also present the risk of damage to nearby property and humans in certain failure scenarios. It is therefore prudent to minimize the scope, frequency, and duration of SCADA component failure. However, it is typical for irrigation districts to focus on corrective (post-failure) SCADA maintenance activities, instead of investing in preventive maintenance.

Preventive SCADA maintenance requires budget and labor investment. However, it is anticipated that it is possible to balance the effectiveness and expenses of a preventative maintenance program with some strategic forethought. For example, preventative maintenance is a major topic of discussion in other industrial applications with similar economic and safety risks. It follows that preventative maintenance can be a valuable tool, especially for complex systems such as SCADA.

This paper provides a survey of several preventative maintenance philosophies and discusses preventative maintenance strategies for irrigation district applications. A template for a preventative SCADA maintenance program is also provided.

Introduction

Electrical, electronic, and mechanical items deteriorate over time and use. To keep systems running, worn items must be replaced and components require routine maintenance. While it is well-understood that mechanical systems require periodic attention, maintenance of Supervisory Control and Data Acquisition (SCADA) systems can be less intuitive, but equally important.

Implementing SCADA maintenance can be difficult because many systems lack:

- *Documentation*. SCADA systems are custom assemblies of hardware and software. User manuals with thorough maintenance schedules may not have been provided by the SCADA system integration firm.
- *Awareness.* While most people familiar with

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Table 1. A range of SCADA system failure results, duration and the corresponding impact level category

Scenario	Potential result	Duration range	Impact level category
A key sensor fails on an automated flow control gate without redundant sensors	Operators are forced to visit the site frequently and make manual gate adjustments	A few hours to a few weeks depending on technician readiness	Low
The calibration of a flow measurement device is modified incorrectly at the head of an upstream-controlled canal	Tail end turnouts are shorted water; irrigators complain	A few hours to a few weeks depending on technician readiness	Medium
A key sensor fails on an automated emergency spill gate without redundant sensors	The canal overtops, and property is damaged	A few hours	High

mechanical systems know to grease bearings and change oil and filters, there are few obvious maintenance tasks with SCADA systems.

- *Budget.* Budgets are generally tight for most irrigation districts and justifying a request to increase the budget for unspecified maintenance is difficult.
- *Experience with failure*. Irrigation district SCADA systems are relatively new and district personnel may not be aware of notable failures that can occur with automated structures.

In the authors' experience, most irrigation districts follow the "fix it when it breaks" philosophy primarily because of the factors listed above, and because it requires less forethought. The down side is that failures tend to negatively impact the level of service provided by the irrigation district. The magnitude of the impact (impact level and duration) depends on the type of failure and availability of both hardware/software and the skilled labor of SCADA technicians.

Not all SCADA component failures result in significant problems; some failures are only frustrating to technicians and operations staff. Examples highlighting the range of SCADA failure impact categories (as defined by the authors) are listed in Table 1.

Because each irrigation district has a unique set of

Continued on next page

circumstances and infrastructure, it is the responsibility of the district to internally assign its own impact levels to various potential failures and failure results. However, for all districts, failures resulting in damage to persons and property is a possibility. It follows that avoiding such high-impact failures altogether is preferred. Avoiding failures in the first place requires:

1. Adequate budget and available skilled labor.
2. A good initial SCADA system design with documentation.
3. A transition from reactive repairs to proactive (preventative) maintenance.

Good SCADA System Design

There are several aspects to "good" design practices. Appropriate hydraulic control and measurement structures help improve accuracy and provide backup services to SCADA systems. Examples of this include emergency spills, sensor stilling wells and applying adequate safety factors for sizing devices such as trash racks and pumps. Other, more SCADA-specific design choices are equally important, such as using redundant sensors for critical and/or control-related signals, alarm notification systems and selecting components with appropriate environmental ratings.

Moving Beyond Reactionary Repairs

When the failure cause and location are easily identifiable, repairing a component failure is relatively straight-forward. This is because the failure inherently defines the "when" (probably as soon as possible) and "what" (replace the component) of the repair needs. Under preventative maintenance, the "when" (or how often) and "what" must be defined.

It is difficult to perfectly schedule preventative maintenance activities. On one hand, repeating the same maintenance activity too frequently can be considered an unnecessary expense. Conversely, delaying maintenance activities increases the risk of a failure occurring. Under good management, striking the right balance requires consideration of the following key factors:

- Budget – to a large extent, maintenance activities are constrained by budgets
- Criticality – prioritizing major infrastructure over lower impact assets
- Flexibility – timely adaption of policies and procedures based on new evidence

There are several philosophies that can be used to guide preventative maintenance activities:

- Basic Interval – Tasks are triggered by the passing of a specific time duration (e.g., daily, monthly, annual).
- Flexible Interval – Basic task intervals are adjusted based on the frequency of identified problems. When maintenance checks repeatedly fail to identify any problems, the frequency of those maintenance checks are extended to minimize costs until problems are more regularly identified.
- Performance threshold – Tasks are triggered when a certain performance threshold is exceeded; requires continuous or intermittent performance monitoring.

Advantages and disadvantages of these philosophies are discussed in Table 2.

For readers contemplating the implementation of a preventative maintenance program, a good starting point is the basic interval approach. As the tasks become familiar and good record-keeping practices develop over time, the next logical step is to transition to a flexible interval program and consider a limited deployment of performance-based maintenance for key sub-systems and components.

Table 2. Advantages and disadvantages of different preventative maintenance philosophies

Preventative maintenance philosophy	Relative up-front capital costs	Relative ongoing labor input	Comments
Basic interval	$	$$$	Capital costs are low, but there is a higher probability of executing maintenance tasks both too frequently and/or not often enough.
Flexible interval	$$	$$	Asset management software may help increase efficiency at a slightly increased capital cost. The additional labor to analyze maintenance results and determine adjustments to maintenance tasks is likely offset by reducing unnecessary tasks in the field.
Performance	$$$$$	$$	Substantial capital investment is required to install continuous performance monitoring equipment; alternatively, intermittent performance testing can also increase costs.

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Maintenance Activities

To help readers better distinguish between different maintenance tasks, key terms and categories are defined in Table 3.

Logistics & Implementation Recommendations

Good record-keeping practices and traceability are critical aspects to successful preventative maintenance programs. Recommendations regarding logistics and implementation details can include:

- Action item checklists are helpful for technicians. The complete list of tasks is no longer executed based on memory but is written and easily transferrable to new employees.

Table 3. Categories of maintenance activities for a typical preventative maintenance program

Category	Action	Example
Visual inspections	Looking for visual defects, deficiencies or problems	Looking for cracks in conductor insulation
	Presence checks	Checking for the presence of spare fuses in the correct type and quantity
Functional testing	Simulating control commands or alarm conditions and verifying on/off functionality	Calling a gate to move up and down and verifying functionality
Performance measurements	Comparing actual performance metrics with minimum thresholds	Measuring the current of a gate actuator and comparing the readings with manufacturer specifications
Benchmarking	Recording and tracking performance or environmental characteristics over time	Recording ambient radio noise over time
Administrative	Tracking maintenance activities over time to identify trouble areas, sites or devices	Entering maintenance logs into a database
	Procurement of tools or replacement components	Purchasing consumables (e.g., fuses) or replacement instrumentation such as sensors
Computers and office software	Implementing firmware updates, replacing obsolete equipment	Replacing hardware and updating software that has reached its official end-of-life, or is no longer supported by the manufacturer/vendor

- A signature or initials from the person doing the work provides traceability and a beneficial transfer of responsibility to perform the work professionally.
- To minimize paperwork and streamline record-keeping, several software options are available to irrigation districts. In most cases, the software would be made available to field technicians on a mobile tablet or similar device. Platform types (but not specific vendors) include:
    - ◊ Web forms. Several cloud-based software platforms provide the background architecture necessary for the development and input tracking of custom electronic forms. In some cases, the forms are developed by the software vendor based on client criteria. In other cases, the district may be able to create its own at any time.
    - ◊ Complete asset management software can include entire software platforms designed for tracking the maintenance of hard and soft assets.

Preventative Maintenance Plan Template

A preventative maintenance plan template is provided in Table 4 as a starting point for discussion and adaption by readers. Table 4 lists several tasks and a preliminary frequency for executing the tasks. If used, it is expected that the template would be modified over time to better represent the specific SCADA system being maintained.

For readers with existing preventative maintenance programs, it is recommended that the template be reviewed and compared to existing program tasks. In many cases, the authors have found many SCADA preventative maintenance programs to be incomplete when compared to the template.

Summary

Implementing a preventative maintenance program is a worthwhile consideration for irrigation districts with sufficient budget and available skilled labor. It is equally worthwhile to periodically evaluate existing preventative maintenance programs, test results and failure events in the field to determine if adjustments to maintenance programs are justified.

All of this requires excellent and organized records. It is anticipated that asset management software tools can assist irrigation district personnel in tracking and updating records. However, the authors are unaware of any irrigation districts using specialized software for preventative maintenance program tracking in the irrigation district SCADA sector currently, despite common use in manufacturing and other industrial sectors.

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Table 4. Preventative maintenance template for consideration and adaption

Category	Subsystem	Frequency	Task	Justification
Electric power source	Any; utility or photo-voltaic systems	3-5 years	Retorque service feeder, branch circuit, grounding, bonding and other critical terminal fasteners	Heat cycling over time can cause loosening of terminals. Loose terminals can cause arcing
			Function test circuit breakers	Circuit breakers, especially some older brands can wear out over time
			Visually check fuses; check for corrosion and test for resistance/impedance	Fuse connections can corrode and be susceptible to oxidation over time
			Test all ground-fault and arc-fault interrupt devices	Verifying safety functions to avoid the risk of damage to persons
	Grounding system	3-5 years	Visually inspect all grounding terminals, conductors and connectors; clean and apply protective coating if necessary	Connections can corrode and be susceptible to oxidation over time
			Benchmark ground resistance/impedance to earth using the fall of potential method or equal	Safety and electronic performance issues can arise when the resistance/impedance to the earth increases
			Benchmark the resistance between key points of the grounding/bonding system	Terminals and connectors can corrode over time, decreasing grounding and bonding performance
	Solar panels	Monthly	Visually inspect for debris and dust on solar panels; clean if necessary	Solar panel shading from dust and debris accumulation will decrease performance
		Annually	Clean solar panels anyway	
			Trim trees to avoid shading if applicable	
		3-5 years	Verify solar panel azimuth and bearing	Wind gusts, seismic activity and vandalism can change the vertical and horizontal pointing of the solar panel; poor pointing will decrease performance
			Retorque bracketry and railing fasteners/anchors	Fasteners can loosen over time
	Solar charge controllers	3-5 years	Confirm temperature compensation is functional	Temperature compensation coefficients need to be changed to match battery manufacturer recommendations; batteries with different coefficients can be used over time
			Check charge voltage setpoints	Multi-stage charging setpoints need to be changed to match battery manufacturer recommendations; batteries with different setpoints can be used over time
			Retorque terminals	Heat cycling over time can cause loosening of terminals. Loose terminals can cause arcing
			Benchmark charge profiles	Multi-stage charging is a specific procedure of applying varying voltage and current to a battery as specified by the battery manufacturer
	Conductors (wires)	3-5 years	Visually inspect accessible conductor insulation for cracking and/or melting	As the conductor insulation and jacket material age, the insulation/jackets can crack, creating corrosion and arcing potential

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SCADA Preventative Maintenance: Reducing the Potential of Unexpected Failures, by Feist, Markow & Burt

(Continued)

Table 4. Preventative maintenance template for consideration and adaption (continued)

Category	Subsystem	Frequency	Task	Justification
Electric power source	Enclosures	3-5 years	Visually inspect panels; clean out debris	Dust and debris can be problematic for electronic equipment, decrease the convective cooling capacity and accelerate corrosion
			Visually inspect conduit penetrations; fill openings with conduit putty	Open conduit penetrations allow insect and rodent ingress
	Batteries (not flooded)	Annually	Visually inspect battery terminals for corrosion; clean and coat with battery terminal protective coating	Heat cycling over time can cause loosening of terminals. Loose terminals can cause arcing
		Annually	Replace lead acid batteries over 10 years old	Lead acid batteries should be expected to last 5-8 years under ideal conditions; the probability of more problems increases after 10 years of age
		Annually	Replace lithium batteries over 15 (?) years old	Lithium batteries should be expected to last 10-12 years under ideal conditions; the probability of more problems increases after 15 years of age
		3-5 years	Retorque terminals	
			Discharge test benchmarking	Batteries lose energy storage capacity as they age; discharge testing is a performance test of a true deep cycle battery requiring special equipment to maintain a target discharge current over a number of hours
Electronic controls	Contactors and control relays	3-5 years	Conduct function testing	Electromechanical devices can wear out over time
			Benchmark coil and contact resistance	
	Digital PLC outputs	3-5 years	Conduct function testing	Electromechanical devices can wear out over time
	PLC general	Annually	Clean off any dust	Dust can reduce heat dissipation and cause over-heating
Instrumentation	Analog and serial sensors	Weekly	Compare sensor reading to a reference measurement	Sensors drift over time
		Annually	Check full range calibration	Sensors drift over time
		3-5 years	Recalibrate sensors (including flow meters)	Sensors drift over time
	Digital switches	Annually	Check functionality	Electromechanical devices can wear out over time
		3-5 years	Check contact resistance	Electromechanical devices can wear out over time
	Spliced connections in the field possibly exposed to weather	Annually	Check connection and apply dielectric grease	Exposed connections can be subject to accelerated corrosion due to environmental conditions
RTU	Vandalism enclosure	Monthly	Check for vandalism or environmental damage on locks and hinges	
	Grounding and bonding system	3-5 years	Benchmark resistance between critical grounding and bonding points	Terminals and connectors can corrode over time, decreasing grounding and bonding performance

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Table 4. Preventative maintenance template for consideration and adaption (continued)

Category	Subsystem	Frequency	Task	Justification
RTU	RTU enclosure	Annually	Inspect the enclosure for debris, leaks and dust. Clean as necessary	Dust and debris can be problematic for electronic equipment, decrease the convective cooling capacity and accelerate corrosion
			Visually inspect enclosure door gasket for damage; replace as necessary	Failing gaskets can increase water and dust ingress
	Conductors (wire)	3-5 years	Check for cracks or other failures in insulation	As the conductor insulation and jacket material age, the insulation/jackets can crack, creating corrosion and arcing potential
	Conduit penetrations	3-5 years	Verify or replace conduit putty seal	Open conduit penetrations allow insect and rodent ingress
	Fuses and circuit breakers	Annually	Check for contact corrosion and function	Circuit breakers, especially some older brands can wear out over time; fuse connections can corrode and be susceptible to oxidation over time
		3-5 years	Re-torque critical conductor terminals	Heat cycling over time can cause loosening of terminals. Loose terminals can cause arcing
	PLC	Annually	Check internal battery voltage	The internal PLC battery provides backup memory functions and needs to be replaced intermittently;
		Annually	Verify backup application files are available	Up-to-date backup files are critical when a PLC fails
	Terminal block	3-5 years	Retorque critical terminal block screw connections	Heat cycling over time can cause loosening of terminals. Loose terminals can cause arcing
	Power supplies	3-5 years	Check the output voltage and AC ripple	Power supply output voltages can change over time or be adjusted incorrectly; AC ripple is an imperfect conversion of AC current to DC current and can cause problems
	Operator interface terminal	Annually	Visually inspect and test for functionality	Interface terminals have a limited lifespan, especially touchscreens with backlights
	Alarms	Annually	Function test critical alarms	Alarms are the first indication of a problem and therefore should be functional
		3-5 years	Test all software and hardware-based alarms	
	Misc.	Annually	Check for spare fuse quantity; verify presence of as-built wiring diagram	Small glass fuses are not always available locally with the correct rating; having wiring diagrams in the field, that are accurate, is critical for troubleshooting issues
Gates and valves	Gates	Annually	Clean and lubricate gate stems; check for misalignment and bending	Gate stems should be clean and greased to minimize wear on the lifting nut; bent stem shafts can be problematic to actuators
	Actuators	Annually	Visually inspect actuator for oil leaks	Losing lubricant can be a problem over time
			Fully stroke actuators that are not moved regularly	Actuators should be operated regularly
			Verify full open/close limits and functions	Correct open/close limits on the actuator are critical to achieve expected performance and prevent damage from over travel
		3-5 years	Retorque mounting and enclosure fasteners	Loose hardware can cause damage
			Retorque branch circuit conductors and motor leads	Heat cycling over time can cause loosening of terminals. Loose terminals can cause arcing

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SCADA Preventative Maintenance: Reducing the Potential of Unexpected Failures, by Feist, Markow & Burt
(Continued)

Table 4. Preventative maintenance template for consideration and adaption (continued)

Category	Subsystem	Frequency	Task	Justification
Gates and valves	Actuators	3-5 years	Replace actuator battery as recommended by manufacturer (5 years for some)	Internal batteries lose capacity over time
			Benchmark actuator operating current	Gates and valve can get more difficult to move over time, potentially overloading the actuator motor
Pumps	Variable Frequency Drives	Monthly	Verify cooling system performance; clean all air filters	Cooling systems can be critical for VFD operation; overheating will result in unexpected nuisance tripping that can be frustrating
		Annually	Visually inspect enclosures and clean dust and debris	Dust and debris can be problematic for electronic equipment, decrease the convective cooling capacity and accelerate corrosion
			Verify backup configuration files are available and up to date	Backups need to be verified intermittently; backup files are critical for VFD replacement and troubleshooting; many VFD allow the complete configuration to be saved as a readable computer file (spreadsheet) for record keeping
		3-5 years	Retorque branch circuit conductors and motor leads	Heat cycling over time can cause loosening of terminals. Loose terminals can cause arcing
Communications / Networking	Radios and accessories	Annually	Benchmark radio Received Signal Strength Indication (RSSI) and Signal to Noise Ratio (SNR) and data throughput	Monitoring the ambient radio environment and specific radio performance is critical for future troubleshooting
			Verify backup radio configuration files	Having access to the latest radio configuration file is critical if the radio needs to be replaced
		3-5 years	Check antenna alignment	Antenna can shift positioning over time
			Benchmark ambient noise levels using a spectrum analyzer	
	Copper and fiber	3-5 years	Benchmark data throughput and percentages of lost packets across key network links using the "ping" test or equal	Data traffic issues in copper and fiber systems can also occur over time
HMI		Annually	Verify HMI automatic backup frequency and/or dates	Automatic backups need to be verified intermittently; backup files are critical for computer hardware replacements
		3-5 years	Test data and application file backup; test redundant hot-swapping functions	
Security	Network	Weekly	Run software security scans	Frequent security scans for viruses, malware, trojans, etc. are easy to schedule automatically
		Annually	Review, test and implement security operating system patches, firmware updates, etc.	Security and firmware updates are provided intermittently by software and hardware vendors
		3-5 years	Review user access privileges, firewall rules, network segregation, etc.	User access privileges and active accounts should be reviewed regularly and updated as needed
	Firewalls and managed switches	Annually	Verify documentation of system/configuration changes	Up to date documentation and configurations are important
			Verify backup configurations for firewalls, managed switches and images of computers/ servers	Backups need to be verified intermittently; backup files are critical for computer hardware replacements

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SCADA Preventative Maintenance: Reducing the Potential of Unexpected Failures, by Feist, Markow & Burt
(Continued)

Table 4. Preventative maintenance template for consideration and adaption (continued)

Category	Subsystem	Frequency	Task	Justification
Security	Firewalls and managed switches	3-5 years	Update firewall rulesets and managed switch configurations	
	Physical	Weekly	Verify physical access controls (locks, gates, etc.); Verify presence of spare keys	Physical security measures can wear or be lost over time
		Annually	Verify/test and lubricate padlocks	
		Monthly	Review security footage for problems	Review security video footage to identify problems in a timely manner
Computers	General	Annually	Clean out dust and filters	Keeping computers cool and dust free can extend their lifespan
		3-5 years	Test HVAC systems	
			Verify and test all backup application files	Up-to-date backup files are critical when hardware failure and replacements occur
			Verify and provide redundant backups for critical archive data	Maintaining redundant copies of critical data is important; consider storing the two copies in separate, secure locations
	Computers (servers and clients)	Annually	Review, test and implement software updates	Software updates occur over time and should be implemented after testing
		3-5 years	Review, test and implement replacement programs for hardware/software without manufacturer support. Replace end-of-life products	
	Mobile tablets and phones	3-5 years	Replace the device	These items are typically consumables and tend to fail or become obsolete after 5 years

SCADA Cyber Security

Recording of Kyle Feist's Presentation at
Reno Water Users Conference
January 2023

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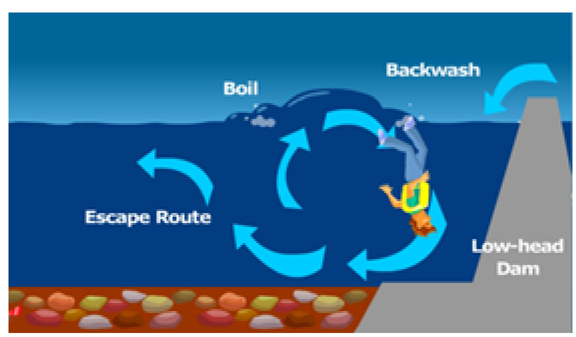
Throwback photo!

Cal Poly student Mary Hamby accepts award as winner of Student Poster Competition from USCID President Brian Wahlin at 2019 USCID conference in Reno, NV



SCADA System Maintenance: An Often Overlooked Necessity

by Kyle Feist and Charles M. Burt, Cal Poly Irrigation Training & Research Center

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. Most tasks and responsibilities are well-understood and achievable.
2. 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.

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SCADA System Maintenance: An Often Overlooked Necessity by Feist and Burt
(Continued)

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 Prerequisites

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.

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SCADA System Maintenance: An Often Overlooked Necessity by Feist and Burt
(Continued)

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

Continued on next page

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	

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

Name	Data Type	DNP address	DNP Class	Variable Type	Modbus Address	Description	Unit	Range (Min)	Range (Max)
Q_FB	Short floating point	17	1	Real	40033	Flow rate over flashboard	CFS	0.0	60.0
Q _SPILL	Short floating point	19	1	Real	40037	Total spill flow rate	CFS	0.0	60.0

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 Eq. 1.

Continued on next page

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

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

* 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"

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

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:

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- 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 on the next page. 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.

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.

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 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 requiring it as part of any SCADA requirement, 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.

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