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COMPARISON OF WIRELESS TECHNOLOGIES FOR REMOTE MONITORING OF CATHODIC PROTECTION SYSTEMS

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ABSTRACT

Impressed current cathodic protection (CP) systems for water storage tanks must be periodically tested in order to ensure proper performance. Wireless remote monitoring technologies provide the ability to monitor CP system performance data from remote locations using modem-equipped personal computers. Data can be provided to a central location through an existing supervisory control and data acquisition (SCADA) systems or through other wireless monitoring systems that can be installed economically. The technology provides capabilities to remotely monitor the cathodic protection system's current and "instant-on" and "instant off potentials," allowing allowed continuous monitoring of CP systems from a central location, and provide personnel with immediate warning of potential corrosion hazards. Case studies are presented for three Army Installations and one Air Force Installation, each with different approaches to remote monitoring of cathodic protection systems for potable water storage tanks and buried pipelines. The benefits of implementation of remote monitoring are the cost avoidance of traveling to remote sites to check each rectifier, and the added capability of instant notification of a malfunction in the cathodic protection system, thus increasing the life of the structures being protected.

KEYWORDS: impressed current, cathodic protection, ceramic anodes, remote monitoring, SCADA

INTRODUCTION

Many Military Installations are spread over large areas and have many water storage tanks that use corrosion protection systems known as "cathodic protection (CP)" systems, which protect the internal or "water-side" of the tank. The outer surfaces of underground pipes, such as water, or gas distribution systems, also must be protected from corrosion in the soil using similar CP systems. In either case, CP systems need to be monitored in order to make sure that they are providing enough voltage and current to maintain the cathodic protection.

Impressed current CP systems work by connecting an anode to the structure, and applying a negative potential to the structure and a positive potential to the anode through a current from an external source, controlled by a rectifier. In recent years, ceramic-coated anodes, usually made by depositing mixed metal oxides onto titanium substrates, have been used as an alternative to the silicon-iron and graphite anodes. The ceramic anode makes corrosion protection available at much less than the life cycle cost of previous technologies and in a size-reduction that permits installation in areas previously too small.

Current cathodic protection monitoring procedures require highly skilled engineer/technician personnel and are extremely burdensome for the maintenance staff. These procedures are often deficient, and do not identify all areas where corrosion protection is either inadequate or non-existent. Furthermore, these locations generally increase with time and remain undetected, until structure perforation and failure. (CP) systems for water storage tanks must be periodically tested in order to ensure proper performance.

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REMOTE MONITORING TECHNOLOGY

Remote monitoring technology [1,2,3,4] allows "on-demand" monitoring of CP systems: (1) from a central location, such as the Office of the Chief of Operations & Maintenance (O&M), or (2) from out in the field by simply driving within 1,000 feet of the CP monitoring station for a given cathodically protected structure, whereupon the CP system status information is instantly up-loaded into a portable computer or personal digital assistant (PDA), and will provide personnel with immediate warning of potential corrosion hazards.

Historically remote monitoring of cathodic protection levels has undergone several evolutions. In the 1980's a system using ground transmitters and receivers placed in aircraft that routinely flew over the pipeline for inspections was promoted. The fly-by system proved uneconomical and ineffective due to communications frequency issues, low transmitter power, and the cost of the monitoring hardware. The remote monitoring systems in use today are: (1) cellular telephone based systems, (2) Supervisory Control and Data Acquisition (SCADA) based systems, and (3) "drive-by" remote monitoring units. These remote monitoring systems both greatly increase the accuracy, frequency, and number of monitoring locations to assure that complete protection is maintained on all the protected structures. Remote monitoring systems also automate the data storage and analysis to identify any areas needing remediation and repair before any significant corrosion occurs.

CASE STUDIES

Case Study 1: Cell Phone Based Remote Monitoring at Army Installation #1
Remote monitoring units (RMUs) installed on two elevated water storage tanks at a large Army Installation in the Southwest. They are identified as Structure #1- 1.5 MMG Elevated Water Tank, and Structure #2– 2.0 MMG Elevated Water Tank. It was anticipated that any Pentium based system with at least 64 Mbytes of RAM, 5 Gigabytes of unused hard drive capacity, 56K modem directly accessing commercial telephone lines and using Microsoft's Windows 95, 98, NT or 2000 would be sufficient (later to include Windows XP) for the projects needs. Each of the two water tank sites was visited and basic data gathered regarding the cathodic protection system operating parameters. These data are shown in Tables 1 and 2. It should be noted that although the cathodic protection system on the Tank #2 was behaving somewhat erratically, it appeared to be providing effective corrosion protection to the tank.

Based on the photos and site inspection, it was determined that the RMU for the Tank #1 could be installed directly on or adjacent to the CP Rectifier unit mounted on the tank support leg, while the other RMU for the tank #2 would be mounted either inside on the exterior of the equipment building in which the CP rectifier was installed at the RMU contractors preference. (See Figures 1a and 1b). Two prospective manufacturers were identified as having relatively inexpensive RMUs (less than $1000/RMU equipment cost) with the desired operating parameters. These parameters are shown in Table 3.

TABLE 1. CATHODIC PROTECTION SYSTEM BASIC DATA FOR WATER TANK #1

Structure 1	1.5 MMG Elevated Water Storage Tank	
AC Input	120V/60Hz/1phase - 3.37A	
DC Volts Max.	30	
DC Amps Max.	8	
Current Output Shunt Rating	100 mV = 10 Amperes	
Operating Data	Rectifier Meter	Test Meter
Volts:	2.1	2.149
Amps:	0.15	1.5 mV where 10 mV = 1 Amp
IR Free Potential (mV):	-980	-980
Potential Set Point (mV)	-980	
"On" Potential (mV):		-1151
Note: This unit is a single circuit unit with no separate riser protection circuit		

TABLE 2. CATHODIC PROTECTION SYSTEM BASIC DATA FOR WATER TANK #2

Structure 2:	2.0 MMG Elevated Water Storage Tank	
AC Input	120V/60Hz/1phase - 3.37A	
DC Volts Max.	30	
DC Amps Max.	8	
Current Output Shunt Rating	100 mV = 10 Amperes	
Operating Data	Rectifier Meter	Test Meter
Volts:	1.8 - 1.9	2.149
Amps:	0.02 - 0.03	0.0 mV where 10 mV = 1 Amp
IR Free Potential (mV):	varied -969 to -987	-980
Potential Set Point (mV)	-978	
"On" Potential (mV):		-1028
Note: This unit has a rheostat controlled secondary output circuit to protect the riser pipe		

FIGURE. 1a- Elevated 2 MMG potable water storage tank at Army Installation #1

FIGURE 1b- Typical RMU installed on water storage tanks at Army Installation #1

TABLE 3. RMU OPERATING PARAMETERS

Characteristic	Description of Requirement
No. of Data Monitoring Channels	2
Ampere Monitor	mV drop across rectifier current shunt with resolution of 0.1 millivolt and minimum RMU channel input impedance of 1 megohm.
Voltage Monitor	Voltage at output terminals of Rectifier with resolution of 0.1 volts and minimum RMU channel input impedance of 1 megohm.
Structure to Electrolyte Potential	Ability to measure both “On” and “Instant Off” potentials using existing permanently installed reference electrode with resolution of 1 millivolt and minimum RMU channel input impedance of 10 megohm.
Options	With 2 monitoring channels, choice would have to be made as to whether (1) system voltage and amperage would be monitored or (2) system amperage and structure to electrolyte potential would be monitored
Installation requirements	System would have to be furnished and installed complete by the same supplier.

The RMU chosen for installation communicated by cell phone modems with 2 channels of data acquisition plus the control channel. It was considered preferable to be able to measure all three parameters of CP system operating voltage, current and potential (both “On” and “Instant-Off”). The cell-phone based RMU hardware and its software were installed and commissioned at Tanks #1 and Tank #2. It took over 6 hours to complete the first installation (including gaining familiarity with local telephone communications requirements), but only 3 hours to complete the second installations and even less time for the software installation including setting parameters for site identification, data acquisition, values to be measured and alarm limits for each channel.

Data accuracy was determined by simultaneously acquiring data using the RMUs and personnel at each site using a precision voltmeter at each site to measure the same data. As can be seen from the data in Table 4, the accuracy of the system during the initial field tests was extremely good and well within the 2% accuracy limits set by the specifications. It should be noted that there were some communication problems with the Tank #2. This occurred due to problems with the telephone company and were immediately resolved by re-setting the RMU at the site. The ability to “log” data on a continuing “real time” basis was also demonstrated

TABLE 4. RESULTS OF POST-INSTALLATION RMU TESTING

Site	Parameter	Voltmeter Value	RMU Value
Tank1	Current (in	0.28 - .30	0.28 – 0.29

	amperes		
Tank 1	Potential "On" (in -mV)	1.140 – 1.145	1.140 – 1.140
Tank 1	Potential "Instant Off" (in -mV)	0.970 – 0.980	0.960 – 0.980
Tank 2	Current (in amperes	0.04 - 0.04	0.04 – 0.04
Tank 2	Potential "On" (in -mV)	1.063 – 1.097	1.050 – 1.145
Tank 2	Potential "Instant Off" (in -mV)	0.970 – 0.980	0.960 – 0.980

Case Study 2: SCADA Based Remote Monitoring System at Air Force Installation

Many military Installations use Supervisory Control and Data Acquisition (SCADA) systems (5) to monitor water levels in potable water storage tanks and to monitor the performance parameters of sewage lift stations.[5] The SCADA system is wireless; it transmits its data to a central control and monitoring station and receives control signals via radio frequency transmission. Control information for the water pumps and sewage lifts station can also be transmitted to the equipment from a central location through the SCADA.

One U. S. Air Force Base in the Southeast is already monitoring impressed current cathodic protection (ICCP) systems on 4 of 5 elevated water potable storage tanks using their existing Supervisory Control and Data Acquisition (SCADA) system. By installing 3 new deep well anode beds, the number of rectifiers in the CP system for underground pipes will be reduced from 40 to 20. The AFB existing SCADA system will be extended by installing 20 additional SCADA transmitting stations at a cost of $10,000 each, at the locations where the 20 additional rectifiers will be installed and they will be interfaced to SCADA units. The SCADA system will transmit the CP data to a central location upon request. The SCADA also provides control of the rectifiers, from a central location at any given time.

The staff has utilized the services of their SCADA system sole source supplier to implement the first CP monitor system at their base on an elevated water storage tank. A schematic diagram of the SCADA based system is shown in Fig. 2a-d. This system can automatically read the rectifier voltage, amperage and the structure potential at the SCADA location. The SCADA Transmitter broadcasts line of site to an antenna on top of a water tower. The signal is re-broadcast to the main SCADA system and then can be stored in and displayed on computers in maintenance staff offices.

A typical SCADA system and cathodic protection system rectifier are shown in Figures 3a and 3b. The rectifier fine control taps are serviced by relays on the SCADA control board, which allow fine voltage control. The rectifier potentials are read directly from the rectifier into the SCADA electronic board. Also, a Hall Effect device (Figure 3b) provides rectifier current readings to the SCADA. From this "proof of concept" system, the Air Force Base has successfully replicated the first system at 3 other water tank locations

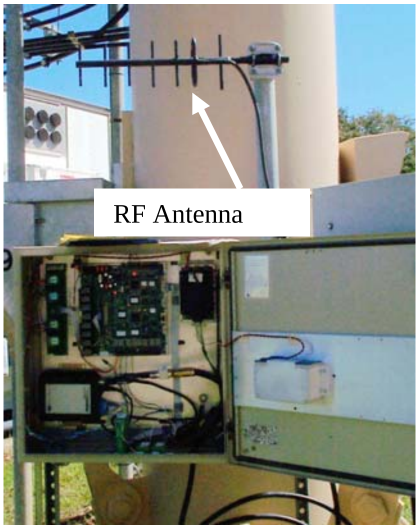

FIGURE. 3a- SCADA system to which CP data acquisition system is interfaced at a USAF Base. Note antenna for wireless transmission of data.

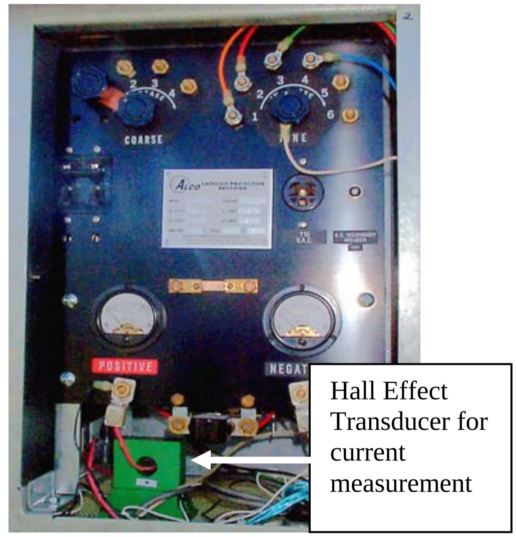

FIGURE 3b- Typical rectifier for CP system installed on elevated water storage tanks at USAF Base

CP data will be stored in the Air Force's Geographical Information System (GIS) database and be accessible through standard USAF GeoBase software. The SCADA system will allow condition based display of data at a central location to allow for graphical display of any CP problems within the GIS. For example, a point with questionable readings could be made to display the problem in yellow or red indications. Analysis software in the GIS will provide the capability to visualize any utility infrastructure endangered by a failure of the CP system. For example, a user could click on a "bad" point and see a display highlighting portions of the utility infrastructure at risk, along with an explanation of system maintenance needs.

The cost of implementation of the SCADA based CP monitoring/control system is very different for locations where existing SCADA already exists versus those locations where such is not the case. For example, at their water storage sites, this AF Base already has a SCADA to control the water level in each tank and to turn various pumps on and off. However, it will cost $10,000 per location to install the SCADA at locations where it does not currently exist.

The only method the USAF Base has for monitoring test stations is by hard wiring the test station leads back to the nearest SCADA system. They have acknowledged that currently, this limits them to measuring only test points within a few hundred feet of the SCADA system. They have also expressed concerns that with the fact that these systems are limited to line of site radio frequency (RF) transmissions, and that in some cases the RF signals are attenuated by leaves on trees during the summer, in which case no CP data can be transmitted.

Case Study 3: Drive by Remote Monitoring Units at Army Installation 2 and Army Installation 3

<u>Army Installation 2.</u> At a second Army Installation, impressed current cathodic protection (ICCP) rectifiers and groundbeds were installed on one natural gas main, one steam main, one water storage

reservoir, and three separate water supply mains. Selection of sites for ICCP installations included input by the Directorate of Public Works staff. This project demonstrated and implemented 6 deep anode impressed current cathodic protection systems (ICCP), 106 drive-by type remote monitoring units (TSDMU) for existing test stations, and 26 drive-by type remote monitoring units (RDMU) (See Figure 4) for existing and new rectifiers. Also, impressed current CP rectifiers and groundbeds were installed on one natural gas main, one steam main, one water storage reservoir, and three separate water supply mains. The six new rectifiers and deep anodes are capable of providing their full rated current output of 30 Amperes DC.

Based on the results of problems with cell phones and expense of installing the SCADA systems, the "drive-by" remote monitoring units (RMU) were installed at Army Installation 2. They were buried in the ground at about 200 impressed current CP monitoring stations. The units were programmed to "wake up" once a month, whereupon they transmit CP data using a low power RF signal. During the time window that the drive-by RMUs are transmitting, CP system maintenance personnel drive by within 0.1 mile of the remote monitoring points, guided by a global positioning system (GPS) map displayed on a laptop or PDA. Since each RMU is tied into the GPS, it broadcasts its location along with its data to the PDA. Once back in the office, the operator can down load the data into a computer where the CP files are stored and further trending analysis can be performed.

The contractor who maintains the ICCP systems said that previously it would take him 2 months to obtain readings from the 106 ICCP test stations and 26 rectifiers that supply the cathodic protection current for necessary corrosion protection of those utilities. Now he can accomplish the same task in 2 days, with automated data saved in a format that allows him to establish trends for early signs that there may be a problem with the system that needs immediate attention.

Army Installation 3. At a third Army Installation, a similar drive-by remote monitoring system was implemented for a new state-of-the art ICCP system on natural gas piping, which included the use of a self-monitoring, self regulating constant output DC power supply energizing ceramic tubular shaped energy emitters (commonly referred to as cathodic protection anodes) buried deep into the earth (deep anode beds). In addition, the drive-by remote monitoring units were implemented for an ICCP system installed in a new 2 million gallon elevated water storage tank, which is this Installation's only source of potable water.

The battery operated remote monitoring system uses 10 – 15 year life replaceable batteries. Installation maintenance personnel drive through the Installation once a month with a standard PC portable computer connected to a small radio transmitter/receiver with a magnetic antenna temporarily mounted on a pickup truck roof (See Figure 5). A GPS unit monitors both the vehicle location and shows all 106 monitoring points distributed around the base on map displayed on the PC screen. Six of these monitor locations measure the output of the six DC power supplies used to energize the ICCP systems, while the other 100 units monitor the corrosion control effectiveness at key locations throughout our buried gas piping system throughout the installation. It is anticipated that it will take as little as 2 hr. to accomplish the entire ICCP survey, compared to the 5-10 days that it would take for a trained technician's time to do the same work. As an additional benefit, the data is then automatically transferred in to an Excel spreadsheet where it is automatically analyzed on a "pass/fail" basis.

FIGURE 4- Left: Typical Pipe Protection Remote Monitoring Units Installed to Interrogate the Pipeline and Transmit System Corrosion Control Effectiveness Data. Right: Remote Monitor Unit with Cap Removed Showing Terminal Connection Points

FIGURE 5- Army Installation personnel can use laptop PC to automatically interrogate and record CP protection levels while being driven by each monitoring station

At both of these installations, for the rectifier sites where no existing SCADA exists (e.g. at rectifier units protecting piping, well casings, etc.), the SCADA would have to be installed first which had an estimated cost of $10,000 per location. This makes the system uneconomic at this Army Installation. As the CP systems only require monitoring once a month at Army Installations #2 and 3, it has been confirmed that personnel can obtain data for the same number of points at a cost of less than $12,000 annually.

Given that these Army Installation have more than 100 monitoring points where no existing SCADA is located (and where none is anticipated to be required for other measurement purposes), the “drive by” system is currently the only economically justifiable system available for automating the data acquisition and recording process

In some cases, direct burying of CP Test Station and monitor unit with 15 year nominal battery life at select locations is possible to prevent damage by normal grounds maintenance work particularly including lawn mowing work. These locations would be “marked” by easily locatable “magnetic” sensors. Implementation of “Drive by” Test Stations that can automatically acquire and transmit both “On” and “Instant-Off” potentials without interrupting impressed current CP system rectifier(s). A further development may allow the measuring of polarization decay where the -850 mV potential criteria is not being satisfied (this is under current development but may or may not be ready during the time of this project implementation, and would not require any new hardware (only software download into CP system test station units).

COMPARISON OF WIRELESS CORROSION MONITORING TECHNOLOGIES

Hardwired RMUs for CP systems require running miles of wiring between the central control system to each monitoring station, and are not practical for military installations. In cases where the SCADA system is not a viable option, cell phone based RMU systems are best used when it is not practical or cost effective to use drive by systems, or when the data must be taken more often than once a month. For example, a remote location many miles way from the central monitoring station would constitute a hardship for maintenance personnel to drive by the location to acquire data. Of course, in order to use the cell phones, it must be established that the cell phone signals for these systems are highly reliable in those locations.

Satellite based systems provide another alternative. They can usually provide CP data readings anywhere and at anytime through the internet. Their initial cost is only about $500-$700 per location, but the data cost per reading per location is generally $5-$10. For a large number of locations to be monitored, this fee could become rather expensive. Also, the satellite based systems are limited to line of site. If a small number of remote locations are to be monitored, the satellite-based monitoring systems may be suitable, however, if a very large number of locations need monitoring, the satellite monitoring system may not be cost effective. A comparison of the attributes of each system is presented in Table 5.

TABLE 5. COMPARISON OF REMOTE MONITORING TECHNOLOGIES

	SCADA-Based System	Drive-by System	Cell phone-Based System	Satellite Based System
Initial Cost	$10,000 per monitoring station	$2,000 per monitoring station	$2,000 per monitoring station	$500-700 per station
Maintenance Requirements	Moderate	Low	Low	Very low
Complexity	High	Low	Low	High
Advantages	-Takes advantage of existing wireless system -can take readings at any time -can control	-Low installation cost - can easily be installed - broadcast frequencies are	-Low installation cost - can easily be installed - can take readings at any time	-Monitor CP system virtually anytime, any where in the world through the internet

	remotely from a central location at any time -can interface with GIS system	pre-approved	- broadcast frequencies are pre-approved - can control remotely any location at any time	
Disadvantages	High cost -Signal path must be properly planned for adequate transmission Signals must be line of site (LOS) -Signals are sometimes lost if there are impediments to LOS - FCC approval is needed for new SCADA frequencies	-Can not monitor from central location; must drive by within 0.1 mile of monitoring station	-Cost of cell phone services -Cell phone signals are sometimes lost in certain locations	-Charges fee/reading/location -Line of site limitations
Recommendation	-Use where existing SCADA system is available, such as water tanks -Do not install additional SCADA systems	-Use where there are no existing SCADA systems -Use when drive by systems are viable	Use where there are no existing SCADA systems -Use where drive by systems would not be viable- very remote areas	Use where there are no existing SCADA systems -Use where drive by systems would not be viable- very remote areas

CONCLUSIONS

The benefits of implementation of the RMUs along with upgrade of CP systems are the cost avoidance of traveling to remote sites to check each rectifier and test station, and the added capability of instant notification of a malfunction in the cathodic protection system. If SCADA systems are already available where the RMUs are to be installed, then the CP monitoring systems should be interfaced to the SCADA system. If the SCADA system is not readily available, either cell phone-based systems, satellite downlinked data systems, or drive-by systems should be implemented. The choice of whether to use cell phones based systems or drive-by systems depends on the reliability of the cell phone signals at those particular locations. By implementing remote monitoring for cathodic protection and ceramic anode-based impressed current cathodic protection systems, the life of the tank, water distribution, or gas system is expected to be extended by 30 years, while reducing the work load of Installation maintenance personnel.

Based on the results of these projects, recommendations are being provided for revisions to Unified Facilities Guide Specifications (UFGS) 13111A “Cathodic Protection System (Steel Water Tanks)” and

UFGS 13112A “Cathodic Protection System (Impressed Current).” These revisions include the specifications and instructions for installing the advanced impressed current cathodic protection systems in conjunction with the “drive-by” remote monitoring units for cathodic protection systems.

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