CASE HISTORIES

Wireless Remote Monitoring of Cathodic Protection Systems

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Wireless monitoring technologies provide the ability to acquire impressed current cathodic protection (ICCP) system performance data from remote locations using modem-equipped personal computers. The technology can monitor the remote ICCP system's amperage, "instant-on" and "instant-off" potentials in a central location, and provide personnel with immediate warnings of system problems. Case studies are presented for one Air Force and three Army installations, each with a different approach for the monitoring.

Many military installations are spread over large areas and have several water storage tanks equipped with corrosion control systems that protect the coated tank interior or "water-side" surfaces. The outer surfaces of the coated water distribution piping infrastructure, usually buried, must be protected from soil corrosion problems using similar anti-corrosion systems. In both cases, impressed current cathodic protection (ICCP) systems, or sacrificial anode protection systems, need to be monitored to ensure that the proper application of direct current (DC) provides a sufficient steel polarization potential that essentially eliminates water-induced corrosion.

Once activated, several components of an ICCP system should be monitored at least monthly, with the data made available to the appropriate maintenance staff. While the data can be acquired manually by a trained technician, discussions with on-site personnel have indicated that between one to two man weeks are necessary to obtain a complete set of accurate data at one of the sites. Several different approaches to decrease the labor intensiveness and increase the timeliness of the data collection and analysis were investigated for the ICCP systems.

Historically, to ease the expense of technicians "walking the pipeline," remote monitoring of land-based ICCP systems has undergone several evolutions. In the 1980s, a system was promoted using ground-based transmitters with receivers placed in aircraft that routinely flew over an oil or gas pipeline. The fly-by system proved uneconomical and ineffective because of the high capital cost of monitoring hardware and aircraft operation costs as well as communication frequency issues and low and inconsistent transmitter power. Today there are several wireless technologies in use, including 1) supervisory control and data acquisition (SCADA)-based systems,[1]

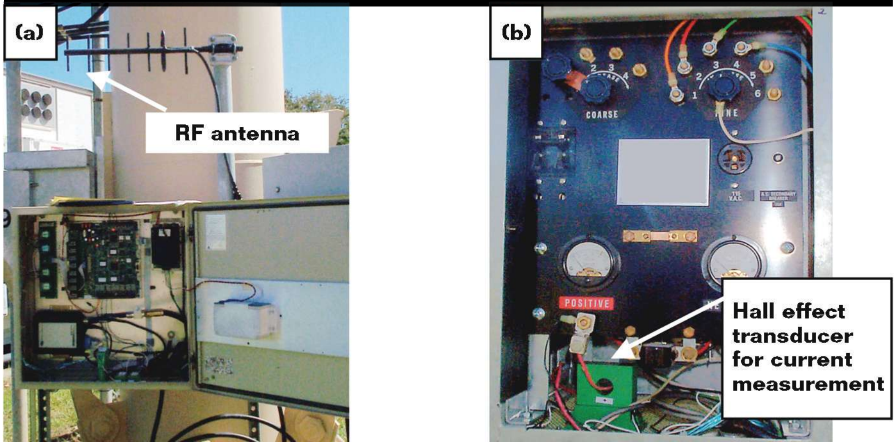
2) "drive-by" remote monitoring units,[2]
3) cellular telephone-based systems,[3-5]
4) frequency hopping spread-spectrum wireless modem-based systems,[4] and
5) satellite-based systems.[5]

Demonstration Systems Installed

Three basic case studies were undertaken to evaluate the different types of wireless monitoring options. One was at an Air Force installation where a SCADA system was already in use for monitoring performance parameters for potable water storage tanks, sewage lift stations, and ICCP for four elevated water storage tanks. A cell phone-based monitoring system was evaluated at an Army installation for monitoring the CP for two water tanks. Drive-by remote-monitoring units (RMUs) were evaluated at two other Army installations for monitoring ICCP systems.

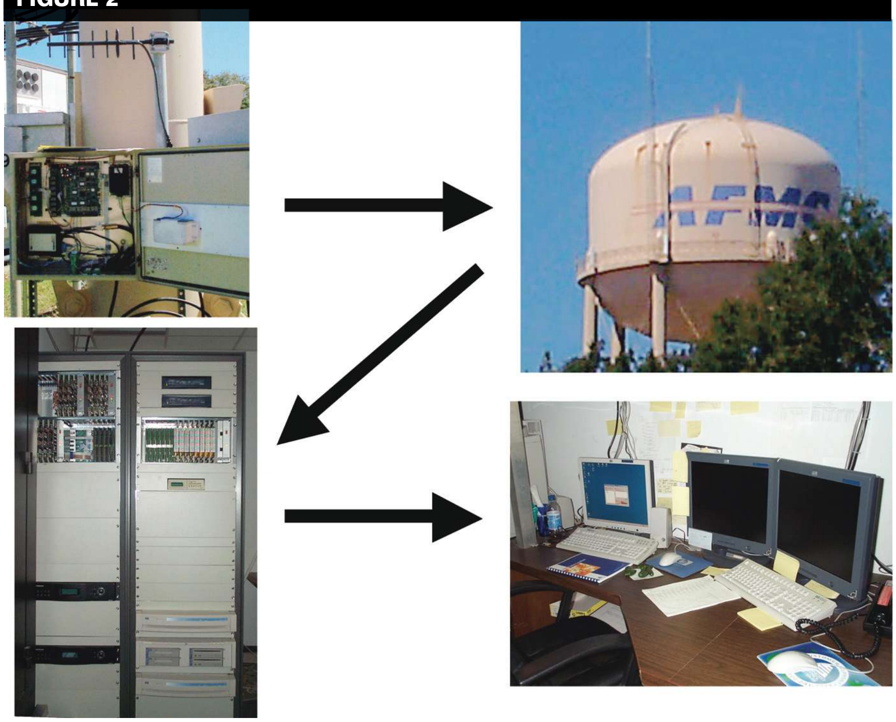
At the Air Force installation, three new deep anode beds were installed, which allowed the number of ICCP rectifiers in the CP system for underground pipes to be reduced from 40 to 20. The 20 rectifiers were reconfigured to allow rectifier current and voltage to be remotely monitored by utilizing the existing SCADA system (Figures 1 and 2). For example, rectifiers were retrofitted with Hall-effect transducers, which produce an output voltage proportional to the rectifier current. This voltage, along with the rectifier voltage and rectifier to structure-to-electrolyte potential, was input as data to the SCADA transmitter. The SCADA facilitated the transmission of the CP data to a central location upon request, and also provided control of the rectifiers from a central location. This system automatically reads the rectifier voltage, amperage, and the structure potential at the SCADA location and the SCADA transmitter broadcasts line-of-site to an antenna on top of a water tower. From this antenna, the signal is rebroadcast to the main SCADA system where it is stored and can be accessed by the maintenance staff from their offices. The data is also stored in the Air Force's geographical information system (GIS) database where it can be graphically displayed to pinpoint any CP problems within the GIS. One benefit/application of this is that the user could click on a suspect reading shown on-screen and see a display highlighting portions of the utility infrastructure at risk, along with an

FIGURE 1



(a) SCADA system to which CP data acquisition system is interfaced at a USAF base; note the RF antenna for transmission of data by the SCADA; (b) CP rectifier control unit provided CP data to the SCADA system. Note the use of the Hall-effect transducer for measurement of the rectifier current.

FIGURE 2



Schematic of a SCADA-based system. CP data from the RMU are transmitted via the SCADA system's remote transmission unit and RF antenna to an antenna on top of a water tower, which relays the data to the master control system at the office where it can be recorded and displayed on a PC.

TABLE 1

Typical RMU operating parameters and CP data

Characteristic	Description of Requirement
No. of data monitoring channels	Two
Ampere monitor	mV drop across rectifier current shunt with resolution of 0.1 mV and minimum RMU channel input impedance of 1 mΩ
Voltage monitor	Voltage at output terminals of rectifier with resolution of 0.1 V and minimum RMU channel input impedance of 1 mΩ
Structure-to-electrolyte potential	Ability to measure both "on" and "instant off" potentials using existing permanently installed reference electrode with resolution of 1 mV and minimum RMU channel input impedance of 10 mΩ
Options	With two monitoring channels, a 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 completely installed by the same supplier

FIGURE 3

Typical cell phone-based RMU.

explanation of system maintenance needs. The cost of retrofitting the existing ICCP system and interfacing it to the existing SCADA system for each of the 20 additional sites was estimated to be $1,000 per location.

For the Army installation using the cell phone-based RMUs on two elevated water storage tanks, one RMU was mounted on the tank support leg adjacent to the CP rectifier. The other tank's RMU was mounted on the exterior of the equipment building in which the CP rectifier was installed. Two manufacturers offered relatively inexpensive RMUs (<$1,000/RMU equipment cost) that provided the desired operating parameters communicated by cell phone modems with two channels of data acquisition plus the control channel. They were able to measure all three parameters of the CP system: operating voltage, current, and potential (both "on" and "instant-off"). These are further detailed in Table 1. The first installation took over 6 h to complete, as gaining familiarity with the telephone communications requirements took time. The second installation took only 3 h to complete 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 verified by manually using a precision voltmeter and measuring the same data as that being transmitted. The accuracy was well within the 2% accuracy limits set by the specifications. The capability of the system to log data on a continuing "real time" basis was also demonstrated. Figure 3 shows an example of one of the commercially available cell phone-based RMUs that was used.

At two Army installations, drive-by type RMUs were demonstrated. At the first of these installations, ICCP rectifiers and groundbeds were installed on one natural gas main, one steam main, one water storage reservoir, and three separate water supply mains. Additionally, as part of this project, six deep anode ICCP systems, 106 drive-by type RMUs for existing test stations, and 26 drive-by type RMUs for existing and new rectifiers were implemented.

The RMUs were located on top of test stations or buried in the ground at ~200 ICCP monitoring stations (Figure 4). The units were programmed to "wake up" once a month, and transmit CP data using a low-power radio frequency (RF) signal. During the time window that the drive-by RMUs are transmitting, CP system maintenance personnel drive within 0.1 mile (0.16 km) of the remote monitoring points, guided by an on-board global positioning system (GPS) map displayed on a laptop or personal digital assistant (PDA) (Figure 5). Each RMU tied into the GPS broadcasts its location and data to the PDA.

Once back in the office, the operator can download the data into a computer where the CP files are stored to perform further trending analysis.[6] This method reduced the time necessary to gather the information/data from two months to only two days. An added benefit is that data are available in a format that allows easy detection of trends and early signs of problems, which can be remediated before they become major difficulties.

At the second Army installation, a similar drive-by RMU was implemented for a new ICCP system on natural gas piping and on a 2-million gal (7.5-million mL) elevated water storage tank. These systems include the use of a self-monitoring, self-regulating constant output. This remote monitoring system is powered by replaceable batteries with a 10- to 15-year life. The data are gathered by driving through the installation once a month with a standard portable PC connected to a small radio transmitter/receiver with a magnetic antenna temporarily mounted on a vehicle roof. A GPS unit monitors both the vehicle location and shows all 106 monitoring points distributed around the base on a map displayed on the PC screen.

Six of these monitor locations measure the output of the six direct current (DC) power supplies used to energize the ICCP systems, while the other 100 units monitor the corrosion control effectiveness at key locations throughout the buried gas piping system. The time required for a trained technician to obtain the data, previously five to 10 days, is now reduced to ~2 h. As an added benefit, the data is automatically transferred into an Excel† spreadsheet where it is automatically analyzed on a "pass/fail" basis. The installed cost of the drive-by RMUs runs about $1,500 per test station.

Another method of collecting CP data is by satellite-based systems.[5] The satellite-based system has the advantage of collecting the CP data readings at any time from any location through the Internet. The installed cost is only ~$1,500 per location, but the data cost is typically $3 per reading per test station. 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. If a very large number of locations need monitoring, however, the satellite monitoring system may not be cost effective. Although we have not used this method for remote monitoring of CP systems, we are currently planning to use it at an Army installation in Okinawa, Japan to gather data on the performance of coatings for metal roofs using underfilm corrosion sensors.[7]

FIGURE 4

(a) (b)

(a) Typical pipe protection RMUs installed to interrogate the pipeline and transmit system corrosion control effectiveness data. (b) RMU with cap removed showing terminal connection points.

FIGURE 5

(a) (b)

Maintenance personnel can use laptop PC (a) or PDA unit (b) to automatically interrogate and record CP levels of each monitoring station during drive-by.

Comparison of the Wireless Corrosion Monitoring Technologies

To use hardwired RMUs for CP systems, miles of wiring must be installed between the central control system to each monitoring station, which is not practical for military installations. In cases where the SCADA system is not a viable option, either because it is not readily available or the number of locations to be monitored makes it cost prohibitive, drive-by RMUs are a good alternative. 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, to use cell phones, it must be established that the cell phone signals for these systems are highly

†Trade name.

TABLE 2

Comparison of wireless remote monitoring technologies

	SCADA-Based System	Wireless Modem System	Drive-By System	Cell Phone-Based System	Satellite-Based System
Typical initial approximate cost (includes equipment and installation)	$1,200 per monitoring station (assuming that SCADA system already exists at nearby test stations)	$2,500 per monitoring station (can be higher due to difficulty in obtaining alignment for line-of-site [LOS])	$1,500 per per monitoring station	$1,500 per monitoring station	$1,500 per station
Additional costs	None	None	None	Monthly charges	Monthly charges and charges for each reading/site
Advantages	—Nominal 20-mi range —Takes advantage of existing wireless system often with tall antennas on water towers —Can take readings at any time —Can control remotely from a central location at any time —Can interface with GIS system	—Nominal 20-mi range —Can take readings at any time from central location —Can control remotely from a central location at any time —FCC-approved spread-spectrum frequency hopping provides secure communications —Can interface with GIS system	—Can monitor many test stations during drive-by —Long-lived maintenance-free on-board battery —No LOS issues due to drive-by requirement —Broadcast frequencies are pre-approved —Distance-limited signals removes security issues with long-distance transmission of information	—Can monitor and control many distant CP test sites from central location —Broadcast frequencies are pre-approved	—Can monitor and control CP system virtually anytime, anywhere in the world through the Internet —Can interface with GIS system
Disadvantages	—Signal path must be properly planned for and adequate transmission signals must be in LOS —Cannot monitor very distant locations (>20 mi) from central points —FCC approval is needed for new SCADA frequencies —Cost is much higher if SCADA system does not already exist near test sites	—Signal path must be properly planned for adequate transmisiton; signals must be LOS; cost may be higher due to this complexity —Cannot monitor very distant locations (>20 mi) from central points —May require installation of tall antennas, which may not be practical	—Cannot monitor from central location; must drive by within 2.0 mi of monitoring station —Cannot control CP rectifiers	—Cost of cell phone services —Cell phone signals are sometimes lost in certain locations —Can incur roaming charges	—Possible high fees per reading/location if there are many stations to monitor —LOS limitations —Subject to loss of service due to satellite outages
Recommendation for use	—Use where existing SCADA system is available near CP test sites (e.g., for potable water tank level readings and control)	—Use where there are no existing SCADA systems near CP test sites —Use where drive-by systems are not viable	—Use where there are no existing SCADA systems near CP test sites —Use when drive-by systems are viable	—Use where there are no existing SCADA systems near CP test sites —Use in remote areas where drive-by systems are not viable —Use when there are a small number of stations to monitor	—Use where there are no existing SCADA systems near CP test sites —Use in remote areas where drive-by systems are not viable —Use when there are a small number of stations to monitor

reliable in those locations. Most cell phone-based systems also require a monthly fee, typically $35. Also, it has been reported that the monthly fee can be higher if the cell phone automatically goes into roaming mode.[8]

Since these evaluations were initially made, the minimum drive-by distance required by the drive-by RMUs has been increased from 0.1 to 2 miles (3.3 km).[7] The measurement of polarization decay where the −850 mV potential criteria is tested for compliance is now a part of the data obtained and retrieved. Some of the CP test stations and monitoring units that had a 15-year nominal battery life were buried to prevent damage by normal grounds maintenance work like lawn mowing. The units' locations can be easily marked and located by installing magnetic sensors that are part of the installation process.

A recent article in *MP* discussed the use of wireless spread-spectrum frequency hopping modems to gather remote data on CP systems, as well as control rectifiers.[4] Although we have not evaluated this technology for remote monitoring of CP systems, we have found that similar, but lower power wireless modems are effective for transmission of data and commands for on-site wireless control of navigation locks operated by the Army Corps of Engineers.[9] The emerging wireless modem CP technology should also be considered as an alternative for remote monitoring of CP systems where an existing SCADA system is not available, and when drive-by RMUs, satellite-based systems, or cell phone-based systems would not be practical. Table 2 compares all five of these wireless remote monitoring technologies, including recommendations for the use of each.

Summary and Conclusions

The benefits of implementing the RMUs, along with an 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 CP 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, wireless modems, or drive-by systems should be implemented. The choice of whether to use the "long-distance" wireless technologies or drive-by systems depends largely on the installation cost, monthly fees, and reliability of the signals at those particular locations. By implementing the most practical remote monitoring technology, based on a comparison of which is best for one's given situation, the life of the tank, water distribution, or gas system is expected to be extended by 30 years, while reducing the work load of maintenance personnel at the same time.

References

1 "Harnessing SCADA Without Undermining Security," *J. of the American Water Works Association* 7 (2004).

2 A. Kumar, L.D. Stephenson, "Comparison of Wireless Technologies for Remote Monitoring of Cathodic Protection Systems," Tri-Service Corrosion Conference 2005, paper no. 06T115, Orlando, FL (Houston, TX: NACE, 2005).

3 V.L. Van Blaricum, W.R. Norris, J.B. Bushman, and Michael J. Szeliga, "Low-Maintenance Remotely Monitored Cathodic Protection Systems," ERDC/CERL TR-01-73, 2001.

4 D.J. Southern, "Remote Monitoring of Cathodic Protection Sites by Radio Frequency," *MP* 47, 6 (2008): pp. 34-36.

5 L. Blankenstein, "Wireless Remote Monitoring for Oil and Gas Corrosion Protection Assets," *MP* 42, 8 (2003): pp. 26-29.

6 A. Kumar, L.D. Stephenson, J. Bushman, "Remote Monitoring of Cathodic Protection and Cathodic Protection Upgrades for Tanks and Pipelines," ERDC/CERL TR-07-25, 2007.

7 L.D. Stephenson, A. Kumar, J. Hale, J.N. Murray, "Sensor System for Measurement of Corrosion Under Coatings," *MP* 48, 5 (2009): pp. 36-41.

8 Private communication with Gregg Steel of Borin Manufacturing, Inc., Dec. 9, 2008.

9 L.D. Stephenson, Patrick Wilson, Ashok Kumar, "Demonstration of Onsite Wireless Control of Lock Operating Machinery," ERDC/CERL TR -01-40, 2001.

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