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Remote Monitoring Equipment for Cathodic Protection Systems

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Foreword

This study was conducted for U.S. Army Center for Public Works under the Facilities Engineering Application Program (FEAP); Work Unit F16, “Remote Monitoring for Cathodic Protection Systems.” The technical monitor was Malcolm McLeod, CECPW-ES.

The work was performed by the Materials Science and Technology Division (FL-M) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. Ilker R. Adiguzel is Acting Chief, CECER-FL-M, and Donald F. Fournier is Acting Operations Chief, CECER-FL. The USACERL technical editor was Gordon L. Cohen, Technical Information Team.

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1 Executive Summary

The Army currently owns and maintains more than 3000 miles of buried natural gas pipeline, 20,000 underground storage tanks (USTs), and over 300 elevated water storage tanks. Cathodic protection (CP) is required by regulation on many of these structures to prevent corrosion. Lack of manpower and money has made it difficult for Army Directorates of Public Works (DPWs) to perform the periodic testing that is required to ensure proper, ongoing CP system operation. Many CP system malfunctions remain undetected until the structure that was supposed to be protected corrodes and leaks.

Several companies have recently begun manufacturing remote monitoring units (RMUs) that are tailored for evaluating CP. This technology allows personnel to conduct measurements on multiple CP systems from a central location so that problems can be detected and repaired immediately. A field evaluation of CP RMUs was performed over an 8 month period to determine the effectiveness of systems from three different manufacturers. Manufacturers were selected based upon system cost, features, and availability, and whether the system is made in the United States. The evaluation at Fort Drum, NY included two identical units from each manufacturer installed on indoor rectifiers. The evaluation at USACERL included one unit from each manufacturer installed on an outdoor rectifier. Readings from the RMUs were compared with readings that were taken using traditional manual methods throughout a variety of weather and operator varied conditions.

Units from only one of the three manufacturers performed successfully. Several new or improved systems have entered the market since this demonstration began. There are also units available that are more expensive or that are manufactured outside the United States. Additional FEAP funding is being sought to demonstrate those systems. In the interim, units that meet the criteria in this guide are a viable alternative to manual CP monitoring.

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2 Pre-Acquisition

Description of the Technology

The Environmental Protection Agency (EPA) mandates the use of cathodic protection (CP) to prevent corrosion of metallic underground fuel storage tanks (USTs) and associated piping (40 CFR 280-281). 49 CFR, which is used as guidance by the Army, requires CP on underground metallic gas piping. Army guidance (ETL1110-3-440) requires CP on a number of structures, including all ferrous metallic natural gas piping, all steel water storage tank interiors, and underground heat distribution and chilled water piping in ferrous metallic conduit in soils with resistivity of 30,000 ohm-cm or less. Lack of manpower and money has made it difficult for Directorates of Public Works (DPWs) to perform the periodic testing that is necessary to ensure that CP systems are operating properly. Many CP system malfunctions therefore remain undetected until the structure that was supposed to be protected corrodes and leaks. It is often too late for corrective action at this point, and the pipe or tank must be replaced prematurely. Life cycle costs increase dramatically because of shorter structure service life. Technology is needed to reduce the amount of human effort required to maintain reliable CP systems.

Remote monitoring equipment allows personnel to collect CP performance data from distant locations using a single modem-equipped IBM-compatible personal computer. This eliminates the need for personnel to travel to field sites to take measurements, dramatically increases the number of sites that can be evaluated during a given time period, and frees personnel for other duties. Use of a modem-equipped laptop computer enables the CP system to be monitored from almost anywhere at almost any time (Figure 1). CP systems on Army installations all across the country could potentially be monitored from a single computer.

CP remote monitoring units (RMUs) can be used to monitor the following parameters:

- Structure-to-soil “on” potential: This is the potential of the protected structure with the CP current applied. This potential is usually referenced to a copper-copper sulfate ($Cu/CuSO_4$) reference electrode.

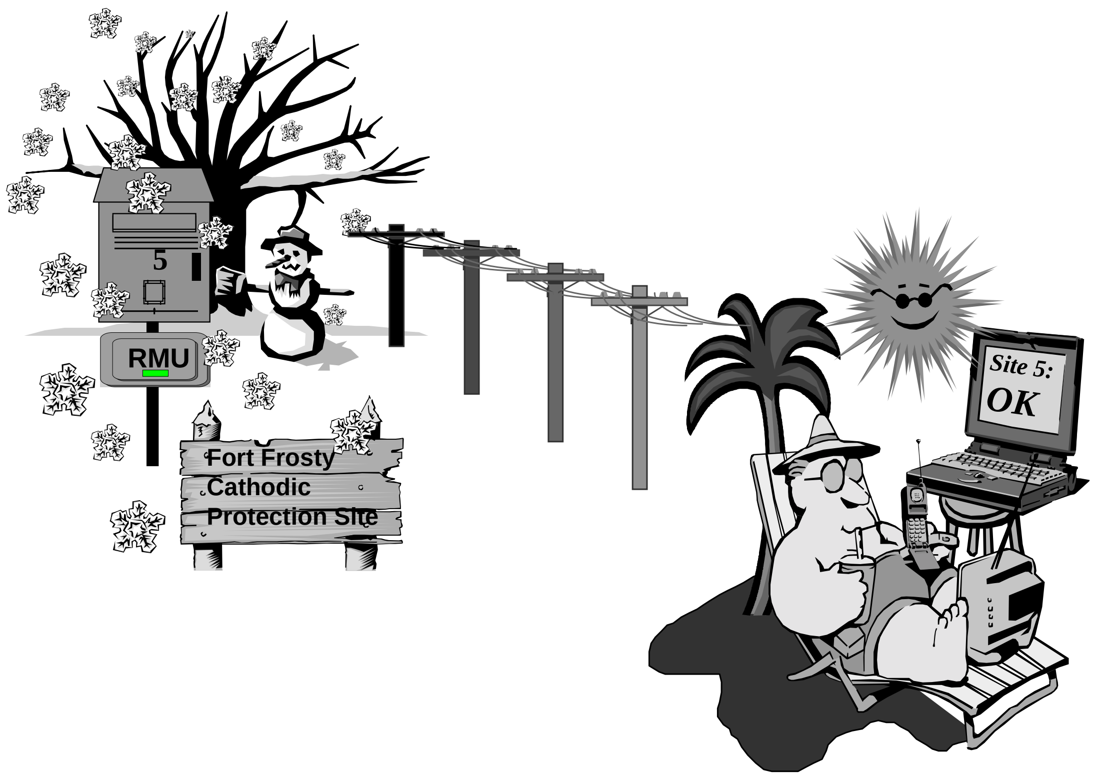

Figure 1. Remote monitoring allows a cathodic protection system to be evaluated from a distant location.

- Structure-to-soil "instant off" potential: This is the potential of the protected structure immediately after the CP current is interrupted. The potential is usually referenced to a copper-copper sulfate ($Cu/CuSO_4$) reference electrode.
- Rectifier DC voltage: This is the output voltage of the rectifier as measured across the output terminals.
- Rectifier DC current: This is the output current of the rectifier. It is usually determined by measuring the voltage drop across a shunt of known resistance and applying Ohm's Law.
- Rectifier AC voltage: This is the input voltage to the rectifier and will usually be 120 or 240 V AC.

A generalized RMU configuration is shown in Figure 2; specific details vary depending upon the manufacturer. This is the configuration that was used in the Fort Drum demonstration. Each RMU is installed near a CP rectifier. A permanent copper-copper sulfate reference electrode is buried near the pipe at each monitoring location and the wire is routed to the RMU. The terminals of the RMU are connected to the CP equipment such that the rectifier output voltage and current, rectifier input voltage, and pipe-to-soil potential (vs. the permanent reference electrode) can be measured. A telephone line is connected to each RMU to enable communication to the computer.

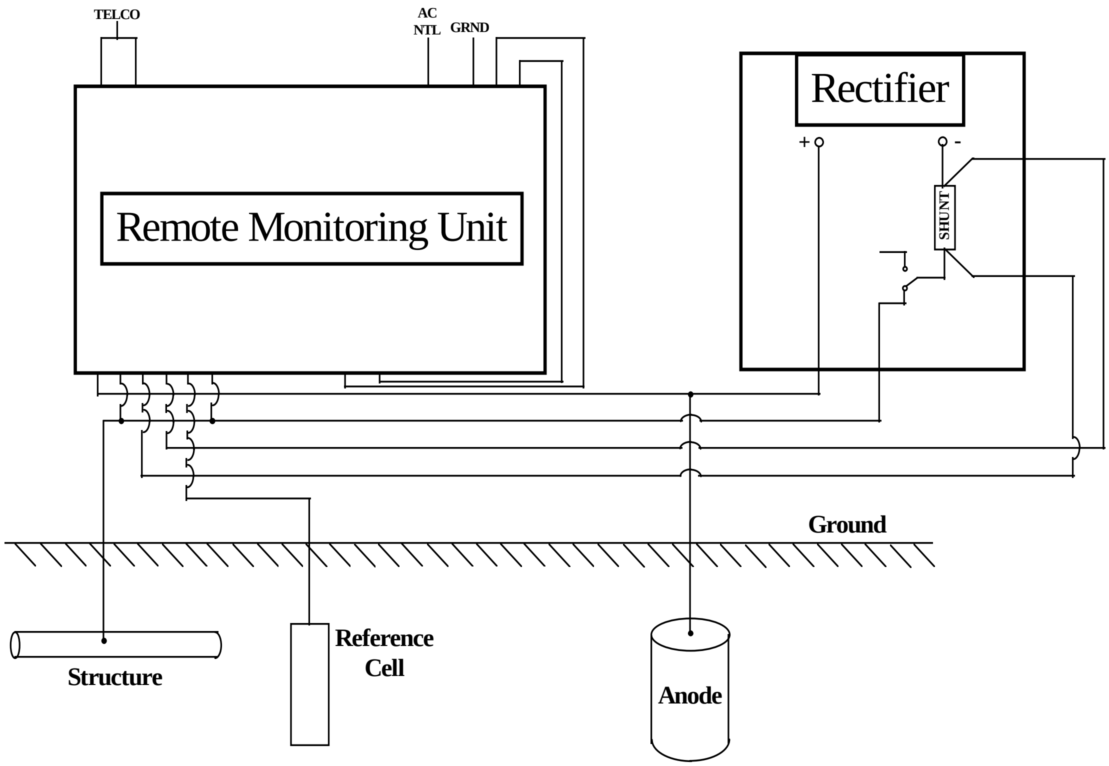

Figure 2. General RMU configuration used at Fort Drum.

After the data have been gathered at the central computer, structure-to-soil potentials may be evaluated against NACE International cathodic protection criteria (NACE International 1992) to determine whether or not the structure is protected from corrosion. Rectifier inputs and outputs may be monitored for significant fluctuations from normal values. Such fluctuations may indicate a problem that needs to be investigated, especially if readings suddenly drop to zero or near zero.

Site Selection

The first step in implementing CP RMUs is to consult the CP system as-built drawings or other applicable CP system records for information on rectifier and test station locations. Most CP RMUs can be installed in a variety of environments, and may be installed either indoors or outdoors. They are typically installed at or near CP rectifiers, but may also be installed at critical structure-to-soil potential test stations. If funding is not available to install monitoring equipment on the entire

CP system, DPW personnel may wish to consider the following questions in deciding where to place the RMUs:

! What is the mission impact if the protected structure fails?
! What are the safety or environmental consequences if the protected structure fails?
! What is the cost of replacing or repairing the protected structure if it fails?
! Does the structure have a regulatory requirement for corrosion protection? (Example: underground fuel storage tanks)
! How much of the protected system will be rendered inoperative if the protected structure fails? (For example, Fort Drum implemented RMUs on the 16" high temperature hot water main that leaves the boiler plant. If this line fails, the entire heating system fails.)
! Is it a known problem area in terms of structure and/or CP system failures?

Each site should be visited before the RMUs are procured to determine if any pre-installation work is required and to gather information that will be needed when the specifications are written. Each RMU site must be equipped with a standard telephone line and an AC power outlet (120 or 240 volts). If these are not available, arrangements should be made to have them installed. (Note: Some of the units on the market that were not tested in this demonstration can communicate via cellular telephone, radio, or satellite.) The location where the unit will be mounted should be determined. Most units will be mounted on a sturdy surface (such as a wall or pole) near the rectifier or test station; some units may be placed inside the rectifier cabinet. It should be determined whether or not special enclosures, tools, brackets, or other installation hardware will be needed so that they can be procured. If the RMU is to be used to measure rectifier outputs, the rectifier's maximum rated output voltage and current should be noted from the label located inside its cabinet. Also note the conversion factor on the rectifier's shunt, which is a component of known resistance that allows rectifier current output to be determined without breaking the circuit. Voltage drop across the shunt (typically in millivolts) is measured and the conversion factor printed on the shunt is used to calculate the current. The conversion factor is usually expressed as "XX millivolts = YY amperes".

If the unit is to be used to monitor structure-to-soil potentials, a suitable location for the permanent reference cell must be found. The reference cell will be buried at the structure depth and approximately 12 to 24 inches away from it. A location should be selected that is clear of any surface obstructions that will interfere with the installation of the reference cell. The wire from the reference cell will be connected to the RMU. This distance should be measured so that the reference cell may be ordered with the appropriate length of wire. Line splices should be avoided if possible.

Common Features and Characteristics

Several features and characteristics were common to all of the RMUs evaluated during this demonstration. They are described in the following paragraphs. It is recommended that units purchased for use at Army installations have these features.

Ability to perform all of the measurements listed above. This includes external relay control or other means necessary for the unit to measure "Instant Off" potential by interrupting the rectifier current.

CP system independence. CP system independence means that the RMUs can be used with any manufacturer's rectifier. Some units (not tested here) only function when used with the manufacturer's rectifier.

Backup battery. Backup batteries are provided in case of power failure.

100% solid state circuitry. Solid state circuitry ensures that there are no mechanical connectors or other mechanical components used except for the solenoid used to interrupt the rectifier current outputs. In general, equipment reliability improves when there are fewer mechanical components.

Industrial-grade components. An industrial component grade ensures that all of the components can operate within a temperature envelope of -40 to 85 degrees C.

Humidity rating. The humidity rating measures a unit's ability to withstand moisture. All of the units tested had a humidity rating greater than 90%. The best performing unit was rated to 100% hose down.

Modem. All units were equipped with a standard Hayes compatible, 2400 baud modem. A 9600 baud modem was optional on some units.

Power requirements. The units that were demonstrated required AC power to operate. The standard was 120 V, but all of the units could be customized to operate at higher voltages. Some of the units demonstrated at Fort Drum were required to operate on 240 volts, while others were required to operate on 480 volts. This must be specified when the units are procured.

Unit-Specific Features

There were several differences in features between the RMUs. These features resulted in significant differences in unit reliability, accuracy, and ease of use. Careful consideration should be given to these features when selecting RMUs for use at an Army installation.

Surge protection. One of the more important variations that showed up throughout the evaluation was the presence of surge protection on unit inputs and outputs. Surge protection varied depending on manufacturer, with only one of the units providing surge protection for all of its inputs and outputs including the data channels, power supply, and telephone line. At the CERL test site, there were two problems that were believed to be caused by the lack of surge protection. In one case, a diode on the circuit board of an RMU without data channel surge protection was damaged when the pipe-to-soil potential momentarily surged higher than -4.0 volts. In another case, the modem of an RMU without telephone line surge protection failed and interfered with communication to all of the other units at the site. It is believed that the modem was damaged by a lightning-induced spike on the line. The RMU circuit board had to be replaced to solve both of these problems. Therefore, an RMU with surge protection on all inputs and outputs (data channels, telephone line, and AC power) is highly recommended.

Data channel type. There are generally two choices for the data channel type: full differential or "common ground." A full differential channel type provides dedicated positive and negative terminals for each channel, which ensures that readings can be gathered from several CP systems without compromising electrical isolation. In a "common ground" channel type, all channels share the same negative bus. This not only prevents isolation of the individual data channels, it also compromises electrical isolation between separate CP systems being monitored by the same RMU. When electrical isolation is compromised, (1) anode service life may be shortened and (2) the affected CP systems may become incapable of providing adequate corrosion protection. During the demonstration, units with full differential channels performed better than those with common ground channels. Two of the Fort Drum sites were equipped with units having full differential data channels. One of the units was employed to monitor two electrically isolated structures simultaneously, and performed successfully and accurately throughout the evaluation. Full differential channel types are therefore a recommended feature, particularly if one RMU will be used to monitor more than one electrically isolated structure.

Quantity of data channels. Some of the manufacturers allow the buyer to specify the quantity of data channels to be included in each RMU. One channel is required for each set of measurement points. For example, monitoring rectifier AC (input) voltage, rectifier DC (output) voltage, rectifier DC (output) current, and pipe-to-soil potential at one location would require 4 data channels. Monitoring the pipe-to-soil potentials on two isolated structures would require 2 data channels. For the units evaluated, the maximum number of channels available per unit was 8. Units with more channels may be available from other manufacturers or may be available in the future from the manufacturers in this demonstration. The unit cost increases with the number of channels. Most installations will require different numbers of channels at the various CP sites due to differences in the configuration of the CP system and protected structures. It is therefore advantageous from the standpoint of cost and ease of installation to purchase from a manufacturer that allows the buyer to specify exactly how many data channels are to be included in each RMU.

Data channel connections. Data channel connections varied between vendors as well. The two choices were either a standard screw type terminal strip or a waterproof quick disconnect. The waterproof quick disconnect interface involved placing a wire with a stripped end into a terminal port and tightening a set screw on the wire to keep it in place. This is a beneficial feature because the data channel connections and the RMU's internal components are protected from moisture and humidity damage. Due to some of the innate installation difficulties with a terminal strip, the waterproof quick disconnect proved to be the more efficient interface method for both installation and maintenance procedures.

Voltage ranges. AC and DC standard voltage ranges varied greatly between the evaluated RMUs. One unit allowed the operator to select from the DC voltage ranges of 0-300 V, 0-40 V, 0-4 V, or 0-400 mV DC, and to select from AC voltage ranges of 0-240 V, 0-40 V, or 0-4 V AC. Another unit only allowed ranges of 0-4V DC and 250 V AC. Based on experience in the evaluation, the added flexibility of extended voltage ranges ensured the capability of the unit to function under the variety of conditions expected with Army wide deployment.

The units tested during this demonstration were required to measure rectifier output voltages between 0 and 60 V DC, rectifier current outputs between 0 and 12 A, AC voltages between 0 and 240 V, and pipe-to-soil potentials of 0 to -4.0 V DC (vs. Copper-copper sulfate reference cell). These requirements will vary for each installation. Before procuring RMUs, Army DPW personnel should determine the ranges within which measurements will be taken and should discuss those requirements with the vendor. For rectifier monitoring, RMUs should be able to measure voltages and currents from zero up to and including the rectifier's maximum rated voltage and current. For pipe-to-soil potential monitoring, it is a good idea to consult CP testing records to determine typical potential values.

Autoranging and software selectable ranges. One of the units provided an autoranging capability and software selectable ranges. The autoranging capability enables the user to contact any remote unit, take readings on all of the channels, and determine the proper voltage range setting for each channel. Software selectable ranges enable the user to directly specify the expected range of voltages. These features allow any input to be interfaced with any channel, which makes installation easier. The autoranging feature would allow a user who does not know how the channels were set up on a particular RMU to contact the RMU, autorange the values, and take readings. The user could then remotely set the voltage ranges for alarms and readings, and determine the nature of the readings from the scaled values.

Data memory. Onboard memory ranged from 8 kilobytes (Kb) flash random access memory (FRAM) to 16Kb conventional RAM on some models. Advantages of FRAM include the ability to reprogram the RMU from a remote PC (useful for software upgrades and unit customization), and ability to troubleshoot the RMU remotely.

Software. Software applications seemed to provide the most dynamic differences between RMU vendors. Since this technology is relatively new, most of the RMU software was upgraded several times during the test period and some significant enhancements were provided. The software applications were important factors in RMU practicality. All of the evaluated software packages were Windows- based, adding the benefit of the Windows interface to a variety of data analysis and reporting programs. None of the units were OLE compliant; however, all of the units saved the requested data in files that were spreadsheet importable. Overall user-friendliness varied depending on the vendor.

Some of the RMUs provided the user with the option of downloading a specified set of readings varying anywhere from unit initialization to the present date, while others were much more limited. The best, and most reliable, solution to the data storage problem was employed by the unit having the capability of storing the data on site. This unit was capable of providing a complete backup data set, as well as exporting data for user-specified ranges of dates. Other RMUs saved the data continually in the same file on the host PC, updating the file with every reading. If the file was erased, all prior readings were lost. The data file size continually increased with these readings and was on the order of 1 megabyte within a month of daily readings.

As mentioned earlier, manufacturers are continually updating their software packages. Some of the newer software developments include the capability of the exporting data directly to any user-specified spreadsheet program. Additional improvements planned for the near future will include OLE compliance for an even simpler incorporation into the Windows environment, and an automatic reporting capability which will enable the unit to contact a remote PC on a scheduled basis to download its readings. Another planned improvement is the addition of an alarm feature, which will notify the user when a reading is outside of user-specified limits. Other improvements will be in the area of security, where access to various unit functions will be limited through the use of passwords. A synchronized interrupt feature will be available in some of the RMU packages, where IR-Free readings will not be influenced by surrounding rectifiers as multiple units can be turned off simultaneously.

Case/Enclosure. Several different types of enclosures were available. An enclosure that is appropriate for the environment should be selected.

Safety. Some of the units involved in the evaluation were not UL listed. Based on experience and recognizing the high current running through large CP systems, a UL listed system is highly recommended.

Relay. A permanent relay switch should be installed with each remote monitoring system in order to interrupt the protective current for "instant off" (IR-Free) structure to soil potential readings. The RMU manufacturer usually supplies these relays as part of the remote monitoring system. The relay switches are the only mechanical components involved in remote monitoring. As a result, they are more susceptible to failure. One of the major problems encountered in the evaluation occurred due to a faulty relay. The relay, which was a spring-loaded solenoid type, tended to stick in the open position after IR-Free readings were taken via remote PC. The result of the open circuit was that cathodic protection current was unable to flow through the circuit, thereby leaving the structure unprotected.

The relay that performed most reliably during the demonstration had the following characteristics:

- UL - listed heavy duty magnetic power relay
- designed for high inrush current applications
- life expectancy of 100,000 operations at full load (life increases when operated at reduced loads or with appropriate arc suppression)
- silver-cadmium oxide contacts (provides extended contact life and resistance to welding when used for heavy inductive loads)

- relay coil is housed in a plastic enclosure thereby preventing damage to the coil
- floating movable contact carrier (provides excellent pressure and wipe between contact surfaces, thereby keeping voltage drop to a minimum between them)
- operating temperature range of -55 ° C to 80 ° C (-67 ° F to 176 ° F)
- operating voltage/voltage range of AC - 6 through 480 Volts, +10%/ -15% of nominal at 25 ° C.

The relay specifications are based on CP system voltage and current requirements. This information should be provided to the RMU manufacturer so that they can select the proper relay for each CP system. For example, the coil specifications for the relays used at Fort Drum included a 240 V input, 1200 ohms resistance, and an amp rating of 25 amperes at 277 VAC. The relays used at Fort Drum had a 25 Ampere contact rating.

Life-Cycle Costs and Benefits

The primary benefits to be achieved from CP remote monitoring include:

1. Cost and manpower demands associated with manual monthly rectifier and structure to soil potential tests can be avoided.
2. Continuous corrosion protection of structures can be readily maintained. CP system problems can be rapidly pinpointed and repaired.
3. Continuous CP results in longer life and fewer failures/repairs for protected structures. This results in overall lower life cycle costs.
4. Documentation of CP system performance to meet regulatory or other record-keeping requirements is simple and automated.
5. Sites that are remote or difficult to access physically can be monitored with ease. For example, large amounts of snow and very cold temperatures in the winter at Fort Drum make it extremely difficult to monitor outdoor rectifier sites.

Benefit 1 listed above can be quantified by comparing the cost of manual rectifier monitoring with the cost of remote monitoring. The annual cost of manual rectifier monitoring is avoided when RMUs are installed because the time to monitor a single site using an RMU is negligible (less than 5 minutes per month). The annual cost avoidance due to eliminating manual rectifier monitoring at a single site is calculated by:

ANNUAL COST AVOIDANCE = 12 x T x R

where T = time in hours required to perform testing at one rectifier site, including travel time

R = hourly labor rate of technician

At Fort Drum, T was estimated to be 1 hour. It is assumed that monitoring would be performed by an engineering technician. The Fort Drum labor rate for a technician is $32.54/hour. This amounts to a total annual cost of $390 per rectifier site.

The installation cost of an RMU includes the cost of the RMU, the reference cell, and the labor for installing it. Based on experience at Fort Drum, it takes about 8 man-hours to install one RMU. It is assumed that the installation is performed by an electrician. The Fort Drum labor rate for an electrician is $24.48. Installation costs for the best-performing unit in this demonstration are:

Item	**Cost**
4-Channel RMU	$1,000.00
Permanent Cu/$CuSO_4$ Reference Cell	$130.00
Labor for unit installation (8 hrs x 24.48)	$196.00
TOTAL INSTALLATION COST	$1,326.00

The simple payback period may be calculated by:

SIMPLE PAYBACK = TOTAL INSTALLATION COST/ANNUAL COST AVOIDANCE

The simple payback period at Fort Drum, based solely upon labor cost avoidance for rectifier testing, is 3.4 years.

Benefits 2 through 5 are difficult to quantify, but add greatly to the justification for using remote monitoring technology. Often, installations lack the manpower or money to perform CP surveys, therefore the absence of corrosion control may go undetected for many years. In some cases, a CP system malfunction is only detected after the structure that was supposed to be protected has begun to leak. Money can be saved through the avoidance of structure repair and replacement costs. Properly-operating CP systems prevent corrosion-induced leaks and prolong the life of the protected structures indefinitely, thereby reducing life cycle costs. For example, Fort Drum has programmed $1.26 million annually during FY96-98 for replacement and repair of heat distribution piping that has failed prematurely after approximately 8 years of service life due to non-existent or malfunctioning cathodic protection. CP could have dramatically extended the life of the system.

It costs Fort Drum approximately $293 per linear foot ($1.55 million per mile) to replace underground heat distribution piping. This does not include the cost of the energy lost from the leaks.

The problem becomes even more serious for underground storage tanks and piping that are regulated by 40 CFR. Absence of corrosion control can result in a Notice of Violation (NOV). If the tank or piping leaks, cleanup costs can range into the millions of dollars.

These sample cost figures clearly illustrate the benefits of maintaining a properly functioning CP system. Regular monitoring and evaluation is required to ensure functionality. CP remote monitoring systems can dramatically reduce the effort required to perform this testing.

3 Acquisition / Procurement

Potential Funding Sources

Army installations can use the Maintenance and Repair “K” account funds to procure the remote monitoring systems.

Technology Components and Sources

For typical applications, the required components are (1) the remote monitoring units themselves, and (2) permanent reference cells.

RMUs tailored specifically for CP monitoring are currently offered by several companies. Since this is a relatively new technology, the market is changing constantly. New units have entered the market since this FEAP demonstration was started. FY97 funding is being sought to demonstrate additional units with improved hardware and software features and capabilities. This will give the Army additional options and guidance for procuring CP RMUs. At the time of this writing, the following company is known to produce RMUs that are manufactured in the United States and have the beneficial features described previously:

M. C. Miller Company, Inc.
341 Margaret King Avenue
Ringwood, NJ 07456
Phone: 201-728-3800
FAX: 201-728-5615

This list may not be all-inclusive.

At the time of this writing, permanent copper-copper sulfate reference electrodes are known to be available from:

Electrochemical Devices, Inc.
P.O. Box 355
Belmont, MA 02178

(617)484-9085 voice
(617)484-3923 fax

Farwest Corrosion Control
17311 South Main Street
Gardenia, CA 90248-3105
Phone: 310-532-9524

This list may not be all-inclusive.

A desktop computer running Microsoft Windows 3.0 or higher is required for data acquisition and analysis. The minimum recommended system configuration includes an 80486-based system with at least 4 Mb of random access memory (RAM), at least 5 Mb of free hard drive space, and a Hayes-compatible modem. A dedicated computer is not required, so most installations will be able to use computer resources already on hand.

Each RMU site must be provided with a telephone line and AC power. Some manufacturers allow multiple units to be monitored from a single telephone line.

Implementation may be performed either by in-house personnel or by contractors.

Procurement Documents

There are currently no Army or Corps of Engineers guidance documents that specifically address CP RMUs or permanent reference electrodes. Installation should be conducted in accordance with the applicable sections of the National Electric Code and Corps of Engineers Guide Specification (CEGS) 16642, *Cathodic Protection System, Impressed Current*, CEGS 16415, *Electrical Work, Interior*, and CEGS 16375, *Electrical Distribution System, Underground*.

Generalized guidelines based on those that were used to procure the Fort Drum systems appear in the following sections. Some items will require installation-specific input; this will be indicated and described in [brackets].

Remote Monitoring Units

1. RMUs shall be able to perform the following measurements [include all or part of these as applicable for the specific site]. The RMU shall contain a total of [insert number] channels.

a. Structure-to-soil “on” potential in the range of 0 to [fill in the maximum voltage expected based on site CP records; -4.0 was used for Fort Drum] Volts DC with a resolution of ±5 mV as referenced to an existing permanently installed copper-copper sulfate reference electrode. [Insert number] channels shall be capable of performing this measurement.
b. Structure-to-soil “instant off” potential in the range of 0 to [fill in the maximum voltage expected based on site CP records; -4.0 was used for Fort Drum] Volts DC with a resolution of ±5 mV as referenced to an existing permanently installed copper-copper sulfate reference electrode. [Insert number] channels shall be capable of performing this measurement.
c. Rectifier DC voltage in the range of 0 to [fill in the maximum rated output voltage of the rectifier(s) to be monitored; 60 was used for Fort Drum] Volts DC with a resolution of ±10 mV. [Insert number] channels shall be capable of performing this measurement.
d. Rectifier DC current in the range of 0 to [fill in the maximum rated output current of the rectifier(s) to be monitored; 12 was used for Fort Drum] Amperes DC. Current measurements shall be obtained by conducting a voltage measurement across the rectifier shunt and using Ohm’s Law to calculate the current. The rectifier shunt is rated at [fill in rectifier shunt rating]. The voltage measurement across the rectifier shunt shall have a resolution of ±0.1 mV. [Insert number] channels shall be capable of performing this measurement.
e. Rectifier AC voltage of [fill in the voltage of the power supply to the rectifier(s) being monitored; this will usually be 120 or 240] Volts AC with a resolution of ± 100 mV. [Insert number] channels shall be capable of performing this measurement.

2. Unit shall have both input and output surge protection on each data channel, the power supply, and the telephone line.

3. Unit shall have full differential channels.

4. Unit shall have a battery backup that is capable of providing power for at least 300 one-minute phone calls in the event of an AC power failure.

5. Unit shall be preconfigured to operate from a [insert available AC voltage] AC power supply.

6. The manufacturer shall supply the external relay control or other means necessary for the unit to measure "Instant Off" potential by interrupting the rectifier current. This relay shall meet the following requirements:

   a. UL listed and CSA certified heavy duty power relay
   b. designed for high inrush current applications
   c. life expectancy of 100,000 operations at full load
   d. silver-cadmium oxide contacts
   e. floating movable contact carrier
   f. operating temperature range of -55 ° C to 80 ° C (-67 ° F to 176 ° F)
   g. capable of being used with a rectifier with a maximum DC output of [insert rectifier voltage and current output specifications].

7. Unit shall have a waterproof quick disconnect-type channel interface.

8. Unit shall possess an autoranging capability, with software selectable voltage ranges.

9. The manufacturer shall include all software required to operate and monitor the RMU.

10. [Optional, depending on site preference] The unit output shall be able to be exported directly into a spreadsheet package.

Future RMU Features

RMU features that may be available in the near future, but are not available at the time of this writing, include:

- storage of user-specified upper and lower limits for each channel and capability to "Auto Call" and identify system ID and error type to PC systems monitoring the station when an "out of limits" condition is measured
- “out of limits” error messages by e-mail
- satellite link for wireless communications
- capability to take readings periodically at user-specified time intervals
- synchronized interrupt of multiple rectifiers
- OLE-compliant data acquisition software to allow sharing of data between applications
- increased security features to prevent tampering.

Army installations should consider adding these features to the specifications as they become available.

Reference Electrode

A permanent copper-copper sulfate reference electrode should be installed with each remote monitoring system. The following specifications are recommended:

A copper-copper sulfate reference electrode shall be supplied which:

1. is suitable for permanent underground installation
2. consists of a saturated gelled copper-copper sulfate element surrounded in a prepackaged backfill mix that is designed to minimize migration of contaminants from the surrounding soil
3. has a design life of 15 years
4. has a stability of ± 5 millivolts
5. has an attached #14 AWG HMWPE lead wire that is [insert number] feet in length.

One reference electrode known to meet these requirements is the EDI Model UR-CUG-SW, which is available from the vendors listed previously. This is the reference cell that was used at all of the CERL and Fort Drum test sites. This electrode comes with a standard 50 foot lead wire, but custom lengths are generally available. The electrode is approximately 8 inches in diameter and 16 inches long, and the total weight is approximately 25 pounds.

Procurement Scheduling

Permanent reference electrodes are generally off-the-shelf items. CP RMUs are generally custom-built to the ordering agency's specifications. For this reason, allow two to three months from the date of the order to the date of receipt. Additionally, as installation requires the burying of permanent reference cells, procurement should be scheduled so that the units are installed when the ground is thawed. Installation of permanent reference cells when the ground is frozen is not recommended.

4 Post-Acquisition

Initial Implementation

Once the protected structures have been identified, sites have been selected, and the RMUs and reference cells have been purchased, four basic steps are required to complete the remote monitoring unit implementation.

Step 1: Installing the Reference Cell

Follow the manufacturer's instructions for installing the reference cell. Reference cells should be buried at structure (pipe or tank) depth and approximately 12 to 24 inches away from the structure's surface. The reference cell wire should be routed to the location where the RMU will be installed. Do not install reference cells when the ground is frozen. Standard safety precautions for underground utility work should be followed. Be sure that the locations of all underground utilities and structures in the area are known and that precautions are taken to avoid damage.

Step 2: Installing the RMU

Mount and wire the RMUs in accordance with the manufacturer's instructions and wiring diagrams. An electrician who is familiar with cathodic protection systems should perform the wiring. The power to the RMU and rectifier should be turned off. Standard safety precautions for electrical work should be taken to ensure a safe installation. RMUs are installed differently depending on the manufacturer, therefore detailed instructions are not given here.

It is important for the person installing the RMUs to understand exactly what needs to be done and where the connections need to be made. During the FEAP demonstration, corrosion engineers prepared detailed wiring instructions to help DPW electricians install the RMUs. The engineers' instructions were intended to supplement the manufacturers' instructions. Samples are shown in the Appendix.

Step 3: Software Implementation

The RMU software should be installed on the computer that will be used to acquire data from the units. Follow the manufacturer's software manual for specific installation procedures. Most of the software is easy to use and only requires familiarity with Windows 3.1 or 95.

Step 4: Data Acquisition

Data may now be acquired from the RMUs following the instructions in the software manual. After installation, accuracy of the data from the RMU should be verified by comparing it with measurements taken by traditional manual methods of CP system testing. For maximum benefit, data should be acquired and analyzed on a regular basis so that any malfunctions can be pinpointed and repaired. The frequency of data acquisition will depend upon regulatory requirements, Army guidance, and installation preferences. Data should be stored for future reference and analysis.

Operation and Maintenance of the Technology

An installed unit meeting the required minimum specifications should require little or no periodic maintenance once proper installation and operation have been verified. In the event of an extended power failure, it may be necessary to replace the RMU's internal battery.

Service and Support Requirements

Implementation of this technology does not require special staffing. Data acquisition and analysis may be performed by an engineer, engineering technician, or other qualified person who is familiar with the basics of cathodic protection system analysis.

Most vendors offer service agreements. The majority of problems that may arise in the RMUs or software can be handled by the vendor via remote diagnostics. Before contacting the vendor for service, check all connections to the unit and check to make sure that power has not been interrupted. Also, it is important to understand that readings do tend to fluctuate somewhat due to the effects of precipitation, temperature, and other environmental factors.

Performance Monitoring

As noted previously, readings taken by the RMUs may be compared with measurements taken using traditional manual CP system testing methods to verify RMU performance and accuracy. These readings should be taken as often as recommended by the manufacturer. In addition, measurements that fall outside the typical ranges of values may indicate a problem with the CP system and/or RMU and should be promptly investigated.

Further information on CP system testing and troubleshooting may be found in Military Handbook 1004-10 or Air Force Manual 85-5. Guidance on Army CP requirements can be found in ETL 1110-3-440. A variety of recommended practices, reference materials, and other publications related to corrosion engineering and cathodic protection are available from NACE International, P. O. Box 218340, Houston, TX 77218-8340, phone 713/492-0535. In addition, USACERL offers annual corrosion courses which include instruction in the area of cathodic protection design, operation, and maintenance.

References

Air Force Manual 85-5, *Maintenance and Operation of Cathodic Protection Systems* (Headquarters, Department of the Air Force, 9 February 1982).

Code of Federal Regulations (CFR), title 40, parts 280-281.

CFR, title 49, part 192.

Corps of Engineers Guide Specification (CEGS) 16642, *Cathodic Protection System, Impressed Current* (Headquarters, U. S Army Corps of Engineers [HQUSACE], 1 October 1994.

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Engineer Technical Letter (ETL) 1110-3-474, *Cathodic Protection* (HQDA, 14 July 1995).

Military Handbook (MIL-HDBK) 1004/10, *Electrical Engineering Cathodic Protection* (Department of Defense, 31 January 1990).

Standard Recommended Practice RP0169-92, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems* (NACE International, April 1992).

Appendix: Sample Supplemental RMU Installation Instructions

Following are two examples of detailed wiring instructions that were prepared to help DPW electricians install the RMUs during the FEAP demonstration. Please note that these are samples only and may not be applicable to your specific RMU configuration. The samples are intended to illustrate a possible approach for making sure the units are installed correctly and to illustrate an appropriate level of detail for the instructions.

M.C. Miller DAX Units

1. Remove rectifier negative cable (this is the structure lead). Splice the negative lead to #12 AWG and route through RMU relay.
2. Use #18 twisted pair wires to connect to terminals of RMU.
3. Connect red #18 to left side of rectifier shunt and RMU terminal #1 of channel #1.
4. Connect black #18 to right side of rectifier shunt and RMU terminal #2 of channel #1.
5. Connect red #18 to positive (anode) terminal of rectifier and RMU terminal #3 of channel #2.
6. Connect black #18 to negative (structure) terminal of rectifier and RMU terminal #4 of channel #2.
7. Splice #18 red to reference cell lead and connect to terminal #5 of channel #3.
8. Splice #18 black to separate pipe lead (running with reference cell lead) and terminal #6 of channel #3.
9. Connect AC power to fuses inside RMU unit. Use caution to match input voltage with RMU rating!
10. NOTE: Provide local disconnect for RMU unit, preferably disconnecting rectifier power as well.

Tomar Systems SMART Units

1. Remove rectifier Negative cable (this is structure lead). Splice to #12 AWG and route to structure terminal in RMU (large right copper lug).
2. Route #12 wire from left large lug in RMU labeled “Rect. Neg.” and connect to lug marked “Negative” in rectifier.
3. Connect reference cell lead to RMU terminal marked “RC.”
4. Connect #12 (min.) wire to RMU terminal labeled “Pos.” and connect in parallel to rectifier terminal marked “Positive.”
5. Ground TOMAR case to earth ground using ground terminal in RMU with a mark resembling an upside down Christmas tree.
6. Plug telephone wire into left most RJ-11 jack labeled “TEL JACK.”
7. Connect separate pipe lead (running with reference cell lead) to RMU terminal marked “STR”.
8. When all power is completed, connect white molded plastic connectors (male & female) to complete battery backup connection.
9. NOTE: Provide local disconnect for RMU unit, preferably disconnecting rectifier power as well.
10. NOTE: These instructions are not necessarily per the manufacturer’s installation manual. The manual pertains to the schematic connection diagram for the RMU “brains” unit itself. This contract specified additional components be provided, which the manufacturers’ manual does not address.