Multi-Zone Cathodic Protection Monitoring for Bridge Applications

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ABSTRACT

The highway bridge infrastructure includes a number of structures in need of replacement or significant rehabilitation work. The respective state's departments of transportation bear the primary responsibility for the integrity and safety of the nation's bridges. These departmental budgets are under significant strain nationwide and this is affecting the challenges involving corrosion prevention on these structures in several ways: Bridge rehabilitation for life extension often involves the introduction of impressed current cathodic protection systems for encased rebar. Limited budgets reduce the number of trained personnel to operate and maintain the systems. The personnel used often have minimal training in the area of cathodic protection. The data forwarded to the CP engineer can be incomplete and there are numerous opportunities for interjection of human error. The field sites from which the data is acquired are often in very dangerous highway locations, making data acquisition both difficult and hazardous. Developing a cost effective way to accurately acquire all of this data in an organized manner and on a timely schedule provided a unique challenge. Standard GSM remote monitoring equipment was designed into a 5-zone (15 channel), "Bridge Zone Monitor System" allowing each zone to be accessed as a discreet site while sharing the communication system with the other zones at the site.

Key words: cathodic protection, multi-zone rectifiers, bridge rehabilitation, remote monitoring.

INTRODUCTION

This case study was undertaken to demonstrate the feasibility of utilizing modified monitoring equipment to provide a cost effective data retrieval system for multiple zone cathodic protection systems deployed at highway bridge sites. Impressed current cathodic protection can be an effective component in extending the life of reinforced concrete structures. One application involves the installation of cathodic protection of the reinforcing rebar in highway bridge decks when rehabilitating aging structures through the process of re-decking. The federal government has issued guidelines for the system specifications, operation, and maintenance of cathodic protection systems used on bridge decks[1], but individual state departments of transportation are primarily responsible for the interpretation and implementation of the guidelines. Qualified field personnel are needed in order to provide timely information regarding cathodic protection system performance. Within the organization participating in this project, there are few trained field personnel specifically assigned to cathodic protection responsibilities. This combined with the absence of the strict, mandated performance monitoring required in the pipeline industry, results in an operational environment in which timely system performance measurements are not always available to the few trained personnel responsible for the operation of the cathodic protection systems. The goal of this pilot project was to provide a cost-effective means of data gathering using standard monitoring technology optimized for the multi-zone rectifier installations typically used in many reinforced concrete CP applications.

PROJECT OVERVIEW

In the state where this project was undertaken there is a single engineer responsible for the operation of the cathodic protection systems at 70+ highway bridge locations spread over a 69,000 square mile area. The cathodic protection systems in use at the site are multiple rectifier systems. Each rectifier is capable of generating a maximum current of 10 amps. The anode system is titanium wire mesh installed on top of the deck, then overlaid with surfacing. Each rectifier supplies current to a zone of bridge decking not to exceed 5000 ft^2. The number of rectifiers included in the system at each site is determined by the number of zones required for adequate protection of the bridge deck(s) at each location. All of the rectifiers at each location are housed in a common enclosure and share a single access panel for voltage, current, and potential connections. The initial system design called for the installation of remote telemetry devices to be installed at each location, and to have the system monitoring function performed by an outside cathodic protection services vendor. Budget shortfalls encountered in the initial installation phase prohibited implementation of this plan. Instead, the monitoring and maintenance of these systems became the responsibility of the local department of transportation signal maintenance personnel. The immediate traffic safety issues associated with signal maintenance dictated the monitoring and maintenance tasks associated with the CP systems were of secondary concern for these personnel. Additionally, the signal maintenance personnel had only basic training in the operation of cathodic protection systems. Budgetary pressure on the public sector increased the difficulty of gathering timely and accurate operational data from field sites. The goal of this project was to deploy a system that provides critical operational data of the cathodic protection systems in the field to the engineer responsible for the operation of the systems, in a timely and cost-effective manner. The project was undertaken in two phases: the pilot system implementation to provide proof of concept, and the project implementation phase currently underway and slated for completion in 2012.

Pilot System Design

The site selected for the pilot installation was a north-south highway overpass on a city belt interstate highway at a significant east-west interchange. The site included two, two-lane overpass bridges divided into four cathodic protection zones. Each zone is associated with a discrete, dedicated rectifier, and all the rectifiers at the site are housed in a single enclosure. The operational readings required from each rectifier were the output voltage, output current, and structure to reference cell voltage potential for each zone. System design factors considered in this project were available space for system deployment, and the ongoing operational and communication costs of the system. Typical available monitoring systems would require multiple devices being deployed at each location due to the input channel limitations of the monitor devices. The solution decided upon used a single communication device (base station) with the capability to receive measurement values from discrete analog measurement devices (modules). Each base station device was configured to communicate with up to sixteen modules using a low power, mesh network, wireless communication protocol. This design allowed a single communication device to transmit the operational values for up to five zones at any given site, incurring a single communication cost. It also allowed for each system to be scaled for the measurement requirements specific to each site location. The system components were mounted on a single panel for installation inside the rectifier enclosure (Figures 1 and 2). Available space required the measurement modules be stacked in pairs, limiting access to the bottom modules. Additionally, the 4 modules used to measure structure to reference potentials were mounted at the bottom of the rectifier enclosure, away from the rest of the system. This was also due to limited space in which to install the system. This approach, however, accomplished the objective for the pilot installation of providing a reliable, cost-effective means of delivering accurate field data to the corrosion engineer responsible for the system. The pilot site was installed in June of 2009.

Figure 1: Base station with eight measurement modules close up view.

Figure 2: Photo of rectifier enclosure with monitor system installed in upper right side.

Pilot System Evaluation

Immediately upon deployment of the pilot site it was determined that Zone 3 of the rectifier was not working. A review of the recent manually transcribed readings from the site did not reflect an out of service condition. This could have been due to any of several factors including misreading the site values, error in transcription, or failure occurring since the last manual reading. Upon evaluation of the problem it was determined that the rectifier for this zone had been manually turned off. The zone was energized and resumed normal operation. The potential values measured on Zone 3 were out of normal range. This out of range condition was confirmed with measurements from a high impedance hand held voltmeter. The cause of the out of range condition was determined to most likely be due to degradation of the reference cell in this zone. Table 1 represents the first two weeks of data derived from the site. The monitoring equipment was programmed to transmit data daily for the initial monitoring period in order to provide a good data baseline. Figures 3, 4 and 5 below are graphs of the readings from Zone 2 reported from November 1, 2009 to April 1, 2010. The rectifiers at this location are set to maintain a constant current level. The voltage and potential levels shifted significantly in this zone over the winter months as the resistance in the bridge deck was affected by winter precipitation and the use of road salts. The drop seen on all graphs on the 8th of March, 2010 is the result of a power failure on that date which triggered an alarm notification on all zones.

The data history also provided a detailed view of rectifier outages and duration as shown in Figures 6, 7 and 8. These figures illustrate a period of rectifier failure in Zone 3 from November 22, 2009 to December 12, 2009. Notification of the system failure was sent to the engineer when the alarm occurred and re-transmitted periodically as an alarm notification throughout the time span the rectifier was inoperable. In the state where this case study occurred, inspections of the systems every two months are suggested, but the only mandatory inspection is done annually. Section 774.5.1 of the Engineering Policy Guidelines[2] covering the inspection and maintenance procedures of cathodic protection systems for this organization require that only the “Spring Evaluation” forms be forwarded to the Maintenance Division for the purposes of permanent record-keeping. This requirement may vary from state to state. Prior to the installation of this monitoring system, an event such as this could go unreported for 12 months and still be technically compliant with the data reporting guidelines established for the cathodic protection systems in the state.

Table 1
Screen Capture from Report History Section of the Monitor Web Interface for the First Two Weeks of System Operation

Time	Rectifier 1 Volts	AC Detect	Rectifier 1 Amps	Rectifier 2 Volts	Rectifier 2 Amps	Rectifier 3 Volts	Rectifier 3 Amps	Rectifier 4 Volts	Rectifier 4 Amps	Testpoint 1	Testpoint 2	Testpoint 3	Testpoint 4
06/16/09 07:04	3.80 V	AC ON	3.49 A	4.00 V	4.66 A	2.40 V	4.34 A	3.10 V	4.32 A	530 mV	570 mV	250 mV	540 mV
06/15/09 09:26	3.80 V	AC ON	3.50 A	4.00 V	4.66 A	2.40 V	4.37 A	3.10 V	4.34 A	530 mV	580 mV	250 mV	540 mV
06/15/09 07:04	3.80 V	AC ON	3.50 A	4.00 V	4.66 A	2.40 V	4.34 A	3.10 V	4.34 A	520 mV	570 mV	240 mV	530 mV
06/14/09 07:04	3.80 V	AC ON	3.49 A	4.00 V	4.67 A	2.50 V	4.36 A	3.10 V	4.33 A	540 mV	590 mV	260 mV	560 mV
06/13/09 11:58	3.80 V	AC ON	3.51 A	4.00 V	4.66 A	2.40 V	4.34 A	3.00 V	4.31 A	530 mV	580 mV	240 mV	530 mV
06/13/09 07:04	3.80 V	AC ON	3.50 A	4.00 V	4.66 A	2.40 V	4.35 A	3.10 V	4.33 A	530 mV	570 mV	240 mV	530 mV
06/12/09 07:03	3.80 V	AC ON	3.49 A	4.00 V	4.67 A	2.50 V	4.36 A	3.10 V	4.34 A	550 mV	600 mV	260 mV	560 mV
06/11/09 07:03	3.80 V	AC ON	3.49 A	4.00 V	4.67 A	2.50 V	4.36 A	3.10 V	4.34 A	550 mV	600 mV	260 mV	570 mV
06/10/09 07:04	3.90 V	AC ON	3.49 A	4.20 V	4.67 A	2.50 V	4.34 A	3.20 V	4.33 A	570 mV	630 mV	270 mV	570 mV
06/09/09 07:04	3.80 V	AC ON	3.49 A	4.00 V	4.67 A	2.50 V	4.37 A	3.10 V	4.33 A	530 mV	570 mV	240 mV	560 mV
06/08/09 11:58	3.80 V	AC ON	3.51 A	3.90 V	4.66 A	2.40 V	4.34 A	2.90 V	4.25 A	520 mV	560 mV	210 mV	510 mV
06/08/09 07:04	3.80 V	AC ON	3.49 A	4.00 V	4.66 A	2.40 V	4.36 A	3.00 V	4.24 A	520 mV	560 mV	220 mV	520 mV
06/07/09 07:03	3.80 V	AC ON	3.50 A	4.00 V	4.66 A	2.40 V	4.35 A	3.00 V	4.34 A	510 mV	550 mV	210 mV	510 mV
06/06/09 07:03	3.80 V	AC ON	3.50 A	4.00 V	4.66 A	2.40 V	4.35 A	3.00 V	4.33 A	520 mV	570 mV	230 mV	530 mV
06/05/09 07:04	3.80 V	AC ON	3.49 A	4.10 V	4.66 A	2.50 V	4.35 A	3.10 V	4.33 A	540 mV	590 mV	250 mV	560 mV
06/04/09 07:04	3.80 V	AC ON	3.49 A	4.10 V	4.67 A	2.50 V	4.37 A	3.10 V	4.35 A	540 mV	590 mV	250 mV	570 mV
06/03/09 14:00	3.80 V	AC ON	3.51 A	3.90 V	4.66 A	2.40 V	4.36 A	3.00 V	4.33 A	530 mV	570 mV	220 mV	500 mV

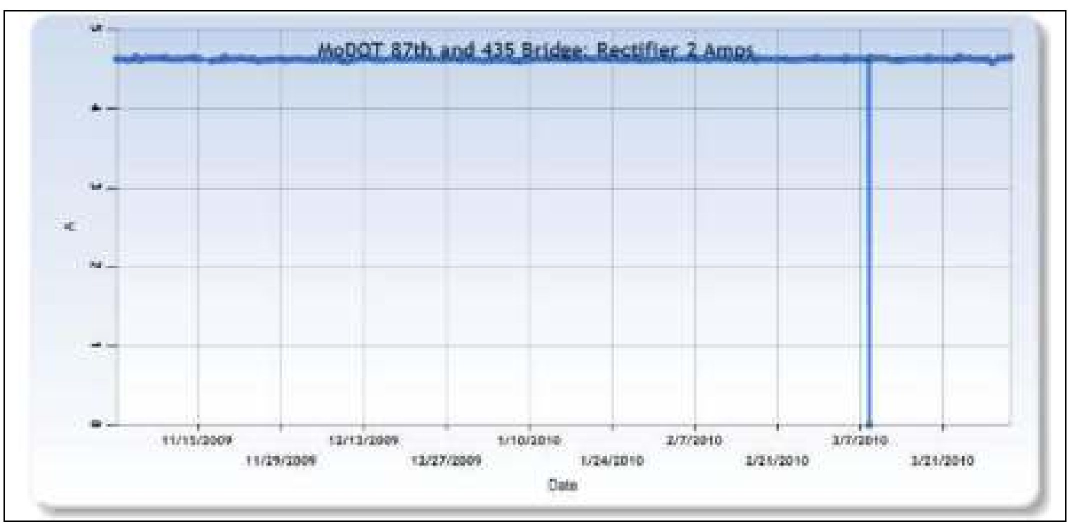

Figure 3: Zone 2 rectifier current output readings from November 2009 through March 2010.

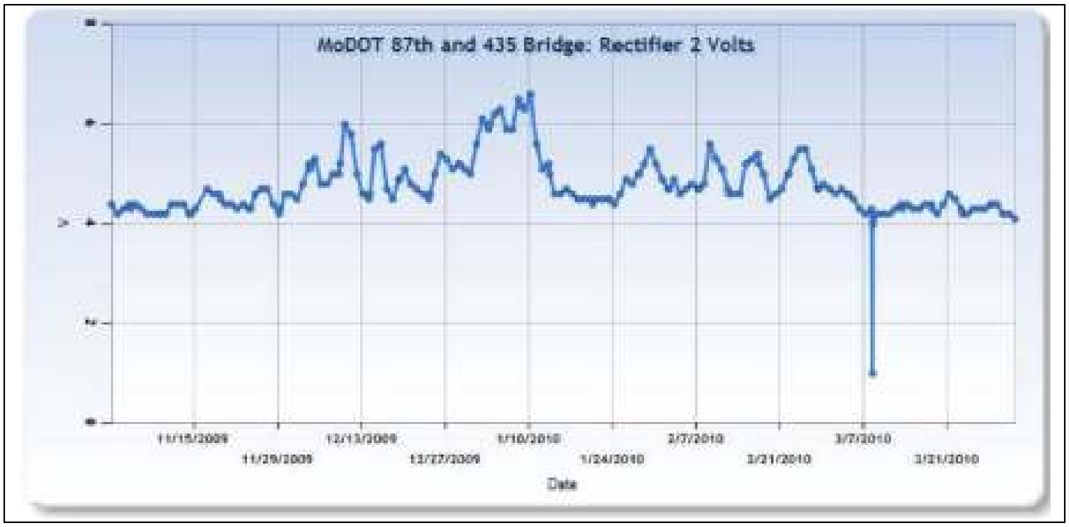

Figure 4: Zone 2 rectifier voltage output readings from November 2009 through March 2010.

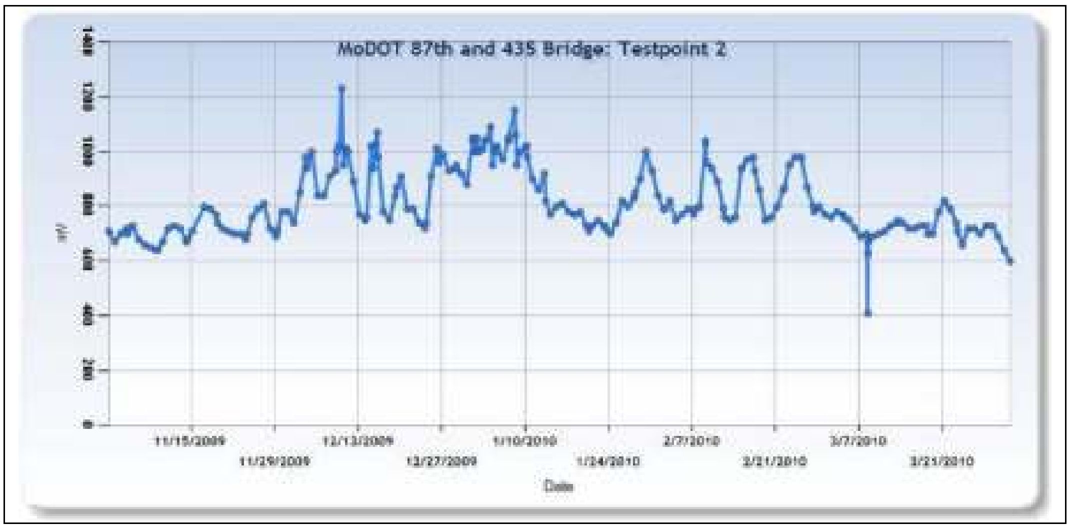

Figure 5: Zone 2 rectifier potential readings from November 2009 through March 2010.

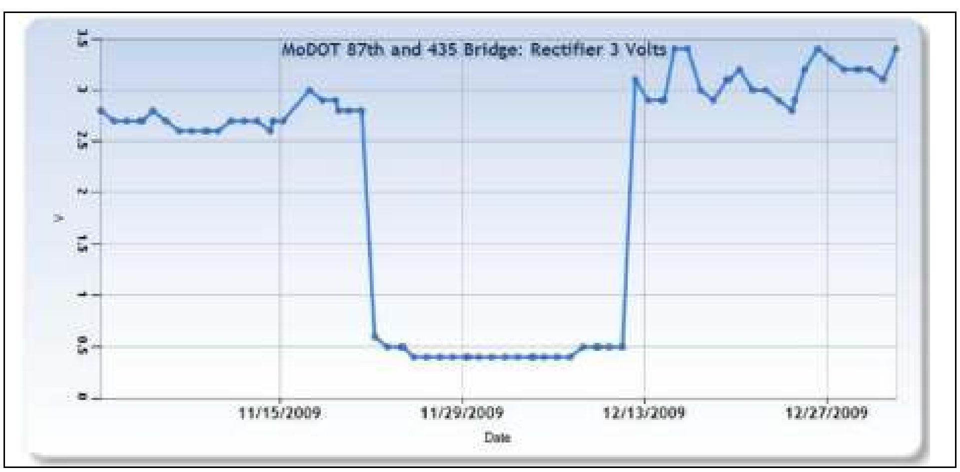

Figure 6: Graph of Zone 3 rectifier voltage output data points showing failure from November 22, 2009 to December 12, 2009

Figure 7: Graph of Zone 3 rectifier current output data points showing failure from November 22, 2009 to December 12, 2009.

Figure 8: Graph of Zone 3 potential data points showing failure from November 22, 2009 to December 12, 2009

Monitor Project Implementation

The pilot system was evaluated regarding performance toward the objectives following nine months of operation. The decision was made that the objectives were met and the project to monitor the cathodic protection systems on bridge decks in the state should move forward. Initial inspections were done at several target locations and many rectifier problems were discovered. At one site the main power to the rectifier enclosure was disconnected altogether. At other sites several of the rectifiers were not functioning at all. None of the problems encountered in the site inspections were known to the engineer or maintenance technicians prior to discovery during these inspections. Several of the target sites were deemed to require too much corrective maintenance to be considered in the first phase of implementation. Following additional site inspections nine structures were selected for the first project phase. The bridges selected included: five 5-Zone structures, three 4-Zone structures, and one 6-Zone structure. The site inspections undertaken to identify target sites for the implementation also revealed a lack of available space inside the rectifier enclosures, at many sites, for deployment of the monitoring systems. A decision was made to integrate the base station communication device with the measurement modules in a NEMA 4 external enclosure designed to be mounted on the rear exterior panel of the rectifier enclosure at the phased one sites. The measurement modules were redesigned as 3-channel selectable range modules rather than dedicated single channel modules. This enabled the enclosure to be designed for 3-Zone, 4-Zone, and 5-Zone configuration using a base station and the appropriate number of modules for the target sites. As each zone would now have a dedicated three channel module capable of reporting voltage, current, and potential for that zone, identification of the measurement block associated with each zone at a site was also simplified. All of the systems under consideration for monitoring range from 3 zones to 10 zones. This design change enabled any site in the system to be fully monitored with a minimum of two systems, meeting a primary objective of minimizing monthly communication costs. The 5-year lithium battery power for the analog measurement modules was reevaluated as well. The integrated enclosures were designed with a 110V power supply capable of supplying operational voltage to the base station and the analog modules in each enclosure, eliminating the non-rechargeable lithium cells. Figures 9 and 10 below show the enclosures installed at a six zone rectifier site.

Figure 9: Interior view of a 3-Zone integrated enclosure.

Figure 10: Two 3-Zone enclosures mounted at a six zone rectifier site.

Changes were also made to the web interface in order to simplify data viewing and data management. Each individual zone was configured for display as a unique site, rather than all of the zones at a given location being displayed together. On the screen view of the site groupings, each zone was configured to display on a separate line creating a unique identity for each rectifier in the multi-zone site. This change resulted in simplifying the data presentation for easier identification of zone specific problems as shown in Table 2. The readability of historical data was improved by displaying the data by zone as in Table 3 rather than in a grouped table including all of the zones. This change also simplified automatic report generation by zone to facilitate permanent record keeping of historical data.

Table 2
Screen Capture of Group View of Most Recent Readings for a Six-Zone Installation

Sites

Assign Sites   Create a New Site   Group Interruption Control   Poll Sites

Status	Int	Site	Last Contact	DC Volts	DC Amps	Potential	AC Detect	Unit Type
OK		Grain Valley Zone 1	09/23/10 09:27	2.20 V	4.30 A	-3,075 mV	AC Available	WD2
OK		Grain Valley Zone 2	09/23/10 09:27	2.70 V	4.30 A	-3,382 mV	AC Available	WD2
!		Grain Valley Zone 3	09/23/10 09:27	0.60 V	0.30 A	11 mV	AC Available	WD2
!		Grain Valley Zone 4	09/23/10 07:03	2.60 V	0.00 A	-3,369 mV	AC Available	WD2
OK		Grain Valley Zone 5	09/23/10 07:03	2.50 V	1.70 A	-4,009 mV	AC Available	WD2
OK		Grain Valley Zone 6	09/23/10 07:03	2.60 V	3.00 A	-1,152 mV	AC Available	WD2

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Table 3
Screen Capture of "Zone-1" Historical Data

Channel History

Time	DC Volts	DC Amps	Potential
09/23/10 09:27	2.20 V	4.30 A	-3,075 mV
09/22/10 09:27	2.20 V	4.10 A	-3,068 mV
09/21/10 09:27	2.30 V	4.10 A	-3,076 mV
09/20/10 09:27	2.30 V	4.30 A	-3,075 mV
09/19/10 09:27	2.30 V	4.20 A	-3,067 mV
09/18/10 09:27	2.20 V	4.60 A	-3,082 mV
09/17/10 09:27	2.50 V	5.00 A	-3,070 mV
09/16/10 09:27	2.40 V	4.80 A	-3,068 mV
09/15/10 09:27	2.30 V	4.50 A	-3,063 mV
09/14/10 09:28	2.30 V	4.40 A	-3,071 mV
09/13/10 16:33	2.00 V	4.30 A	-3,047 mV
09/13/10 09:27	2.30 V	4.50 A	-3,072 mV

CONCLUSIONS

The problem this project set out to address was to deliver the critical data necessary to ensure the cathodic protection systems installed on highway bridges to the personnel responsible for the operation and maintenance of the systems. Due to factors including, but not limited to, inadequate training of field personnel, task priorities of multi-purposed personnel, system and equipment failure, and budgetary concerns, accurate and complete data was not getting to the responsible personnel within the organization. The primary concerns regarding the use of remote monitoring systems at these locations were reliability and operational cost. Advances in the equipment available for cathodic protection remote monitoring, driven by the needs of the pipeline industry, have increased the reliability of remote systems over the last decade as well as lowering monitoring costs. Ongoing communication costs were minimized by combining the data payloads from all of the zones at a location into a single data bundle transmitted via a single communication device. The web-based desktop data interface allowed the data to be displayed in a variety of logical forms simplifying usage. The goals established when embarking on this project were accomplished and the necessary operational data is now being transmitted to the responsible individuals in a timely and cost-effective manner. The increased amount of accurate data provided as a result of continual monitoring will allow the user to graph performance data in order to develop trend models and predict system degradation. This will allow maintenance and repair resources to be prioritized more efficiently.

FUTURE CHALLENGES

The process of evaluating sites, selecting target sites, and installing the equipment at the sites was eye opening. Approximately fifteen to twenty sites were inspected and evaluated for monitoring in this first phase of the project. All sites had operational problems. These issues ranged from individual zones malfunctioning to the entire system at a site failing to operate. The majority of these problems were not previously known to the operating engineer. Some sites were eliminated from consideration for the initial phase due to an inability to address the site issues within the time frame established for implementation of the project. There was a lack of trained personnel available to properly inspect, evaluate, and maintain the CP systems at these sites. Only a part of the issue is addressed with the implementation of the monitoring program. Equipment failures occurring at the sites will now be identified in a timely manner, but due to limited availability of qualified technicians, the required repairs and maintenance will still likely be delayed. This case study focused on one state's issues in dealing with the complexities of operating and maintaining their cathodic protection systems on highway bridges. This is not necessarily representative of the nation as a whole. However, this sector of the cathodic protection industry deserves the same focus and attention as the pipeline sector. Industry initiatives such as the "Bridge Life Extension Act" would go a long way toward standardizing practices and establishing common compliance guidelines. Regulated pipelines operated by corporations recognize the need for trained, qualified personnel to keep the corrosion protection systems operating optimally. This case study suggests the entities responsible for operation and maintenance of systems used on our nation's highways may be lagging behind the pipeline industry in this regard. Additionally, the public sector is increasingly affected by severe budget shortfalls at the state and federal level. These same budget concerns drive initiatives to extend infrastructure life through rehabilitation rather than replacement. As use of cathodic protection becomes more widespread in our highway system it is imperative that operational guidelines are standardized and adhered to. Significant advances in cathodic protection technology are occurring at a rapid rate. These entities that fall outside of the core pipeline industry must be encouraged to invest in knowledgeable personnel in order to be able to fully take advantage of this technology and ensure the integrity of our public infrastructure.

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