INNOVATIVE PLATFORM FOR THE MANAGEMENT OF MULTIPLE CATHODIC PROTECTION SYSTEMS

M. Cheytani[1*], S. Cheytani[2], A. Cheaitani[3]

[1, 2 and 3]*Remedial Technology Pty Ltd, NSW, 2111, Australia*

**Corresponding author email: mail@remedialtechnology.com.au*

ABSTRACT

Over the past forty years, impressed current cathodic protection (ICCP) technology has been highly effective for the corrosion protection of reinforced concrete bridges and wharves in Australia.

One of the key requirements of ICCP systems is the ongoing maintenance and testing over the life of the systems. Establishing long-term maintenance plans and the costs associated with site inspections for functional checks and ongoing testing has sometimes been problematic.

Recent major advances in communications hardware and software, particularly in terms of improved reliability and lower costs, has driven new innovations in remote monitoring and control systems. These improved capabilities can provide an effective platform for the monitoring and maintenance of multiple cathodic protection systems.

This paper includes an example of a platform known as CPMS (Cathodic Protection Management System) which has been utilised by several CP system asset owners in Australia in recent years. The system allows for remote functional checks and testing to be performed securely from an off-site computer. The automated system also allows for 24/7 monitoring of CP systems and manages alarms, maintenance planning, historical documentation, original specifications, as-built drawings, maintenance and performance records.

This paper details the innovations in CPMS and the capabilities and efficiencies it offers asset managers who operate multiple cathodic protection systems.

Keywords: Corrosion, cathodic protection, infrastructure, maintenance, ICCP, CPMS

1. INTRODUCTION

Reinforced concrete is a composite material that relies on the high compressive strength of concrete and the high tensile strength of steel for its mechanical performance. The concrete which encases reinforcing steel has good anti-corrosion properties. This is due to the hydration process of the concrete which leads to the formation of hydroxides and an increase in the pH level of the cement to around 12.5. This pH level allows the formation of a stable oxide layer on the steel surface, which slows down the kinetics (rate) of corrosion of the steel reinforcement within the concrete structures Reinforced concrete failure is caused by the corrosion of the steel reinforcing bars as a result of the destabilisation of this oxide layer. When the passivity of the steel partly or completely breaks down, either as a result of carbonation or chlorides affecting the concrete, corrosion of the reinforcing steel may initiate. The chloride ions react with the passive oxide layer on the steel surface. This reaction disrupts the passive layer and leads to the formation of soluble iron chloride compounds. This means that the electrochemical potential of the steel locally becomes more negative and forms anodic areas, while other portions of the steel with the passive layer intact will act as catchment areas for oxygen and will form cathodic areas [1].

Due to the substantial economic significance of corrosion problems for reinforced concrete structures, there have been significant attempts from the early 1970s until today to improve reinforced concrete quality by changing the material properties of both the steel reinforcement and concrete and/or by applying corrosion measures during construction. For concrete, the improvements include the use of high-performance concrete in conjunction with protective coatings, thicker cover to steel for certain concrete elements, and the use of corrosion inhibitors in the concrete mix. For steel, improvements include the use of stainless steel, galvanized steel and epoxy coated rebar instead of, or in conjunction with carbon steel. In various applications where a 100-year design life is specified, cathodic prevention has also been applied effectively during the construction phase.

Irrespective of the material improvements of reinforced concrete, corrosion of reinforcement is still a major durability problem, and in particular for structures exposed to chloride contamination.

During the past 30 years, various electrochemical protection systems have been used in Australia in conjunction with the repair of chloride contaminated structures. These systems include impressed current cathodic protection, galvanic based anode systems and more recently, various types of hybrid anode systems. The bulk of the systems were designed in accordance to the NACE Standard, the European Standard, and the Australian Standard for cathodic protection [2, 3 and 4].

While there is an overall acceptance that in most cases impressed current cathodic protection (ICCP) systems can achieve the best outcomes in terms of corrosion protection that meets the applicable standards, one of the main perceived disadvantages of ICCP is the need for ongoing maintenance and monitoring over the life of the system.

For galvanic anode systems, generally the performance of these systems is questionable in terms of whether they can achieve corrosion protection in accordance with the applicable standards. Nevertheless, in recent years these systems have been heavily promoted on the basis that there are no requirements for ongoing monitoring.

It is acknowledged that the reliability of some ICCP control systems and the costs involved for ongoing monitoring and maintenance has encouraged various asset owners to select substantially lower performing galvanic anode systems in order to eliminate the need for ongoing involvement with the monitoring of ICCP systems.

However, recent major advances in communications hardware and software, particularly improved reliability and lower costs, has driven new innovations in remote monitoring and control systems. These improved capabilities in conjunction with the use of an online monitoring and maintenance platform such as the one presented in this paper, has made the entire monitoring and maintenance process more routine, low cost and reliable.

Asset owners now have the opportunity to select corrosion protection systems that can deliver full corrosion protection to their structures while implementing state-of-the-art management systems that can make the entire monitoring and maintenance process for ICCP systems more transparent and simplistic.

This paper will present the key aspects of an online platform used for the maintenance and monitoring of over 60 cathodic protection systems operating on Australia's infrastructure assets.

2. What is Cathodic Protection?

Impressed current cathodic protection (ICCP) is a proven electrochemical technology applied to reinforced concrete structures. ICCP promotes the development of steel passivity as a result of the production of hydroxyl ions at the steel-concrete interface to stabilise the protective passive film. In addition, the direct effect of CP includes shifting the steel potential to more negative values, which inhibits the corrosion of iron, and moves the chloride ions away from the steel and towards the anode [5].

There are various types of impressed current anodes applied to atmospherically exposed reinforced concrete. In Australia, the most commonly used types of anodes are mixed metal oxide (MMO) mesh or ribbon anodes (installed in a cementitious overlay or in grout filled chases), and MMO discrete anodes (embedded in drilled holes in the concrete).

When steel corrodes in concrete, the process is comparable to that of a battery. In a battery, electrons are generated because two dissimilar metals are exposed to an acidic solution (paste or gel in practical batteries) that corrodes one metal and creates a harmless reaction in the other. This corrosion reaction at the 'anode' generates electrons that are consumed by the 'cathode'.

For the steel reinforcement that corrodes in concrete, one very small area is the positive pole (anode) and another much larger area is the negative pole (cathode). The corrosion current flows out of the steel at the anode (the corroding part), passes through the concrete and into another part of the steel where there is no corrosion occurring (the cathode). This current flow is called the corrosion circuit and the steel dissolved at the anode forms iron dioxide.

In a practical battery, the electrical connection between positive and negative poles can be disconnected. The circuit is then broken and the dissolution of metal stops. However, in concrete, the corrosion circuit is buried in the structure and the electrical current running through the concrete cannot be disconnected. The only method of stopping the current from running through the concrete is to provide new current from an external source via an external anode in/on the concrete. The flow of electrons between the new anode and the reinforcing steel changes the previously positive poles (anodes) into current receivers. Thus, all of the steel reinforcement becomes a negative pole or cathodic, and hence the name 'cathodic protection'.

The application of cathodic protection for concrete structures transforms the environment around the reinforcement over a period of time. The negatively polarised metal surface repels the chloride ions from the steel while the hydroxide ions generate at the steel's surface. These hydroxide ions are responsible for inducing passivity of the reinforcement [6].

It is important that the design of an ICCP system is carried out within the guidelines stated in the latest revisions of the applicable standards and by experienced cathodic protection engineers. This is to eliminate any side effect associated with the long-term operation of the system such as grout acidification and high voltage due to reduced system capacity. Etc.

3. Monitoring requirements for ICCP systems

Australian Standard AS 2832.5-2008 (R2018) states that *"the procedures and intervals for routine inspection and testing vary from one cathodic protection system to another and are dependent on factors including the structure type, the CP system type, the reliability of the power supplies, the environment and the vulnerability to accidental or deliberate mechanical or electrical damage. In addition, those systems provided with electronically data logged or electronically data transmitted performance monitoring systems may require less frequent physical inspection as the routine testing can be undertaken automatically. Further to this, AS2832.5 states that consideration shall be given to* *extending the intervals between routine inspection and testing if no fault, damage or significant variation in system performance is indicated by successive inspections/tests". Typically, the functional check is undertaken monthly in the first year of operation and, subject to satisfactory performance, thereafter at 3-monthly intervals. Typically, the performance assessment is undertaken at 3-monthly intervals in the first year of operation and, subject to satisfactory performance and review, at 6-monthly to 12-monthly intervals thereafter."*

Based on the above monitoring requirements, it can be concluded that manually operated systems would require extensive physical inspections for the purpose of performing functional checks and performance testing. The standard outlines that less frequent physical inspections can be achieved for systems with facilities for automatic transmission of data.

4. Concept of Cathodic Protection Management System (CPMS)

Cathodic Protection Management System (CPMS) is an advanced management tool for the efficient monitoring and maintenance of cathodic protection (CP) systems.

The online management system offers a simple and efficient platform for the maintenance and monitoring of multiple CP systems. The platform includes a live monitoring portal which allows the asset owner to view on their PC real time monitoring data from the cathodic protection system. In addition, CPMS allows permanent access to all historical performance data, construction drawings, operational manuals and maintenance records for the CP systems.

<u>The attributes of this management system include:</u>

- A permanent database for the CP systems incorporating all key system data which is required for the long-term CP system operation and the maintenance of the structures.
- The platform can monitor the continuous delivery of CP current to all structures at all times.
- The owners of structures can verify the status of the CP systems allowing for the systematic planning of maintenance work to the structures.

CPMS allows for the immediate identification of any issues which may affect the corrosion protection of the structure. Any issues are promptly identified and can be rectified within the appropriate time. One of the unique benefits of CPMS is the elimination of duplicate reports and documents which are irrelevant (and often slow down and clutter any decision-making process). With the management platform, the asset owner is directed only to the key important facts about the CP system and the actions required and this makes long-term maintenance planning transparent, simple and achievable.

An initial major site audit of the CP systems and the structures is a central component of the CPMS. Based on our experience, every audit performed has revealed some non-performance issues with the CP protection of the structures. Some issues are minor while others reveal serious deficiencies in the protection systems with some problems having been consistently overlooked for years.

5. Typical applications

CPMS can be setup for multiple systems operating on various structures and can provide a global view of the status and performance of each CP installation. An example of the main page of CPMS setup for three systems is demonstrated below in Figure 1.

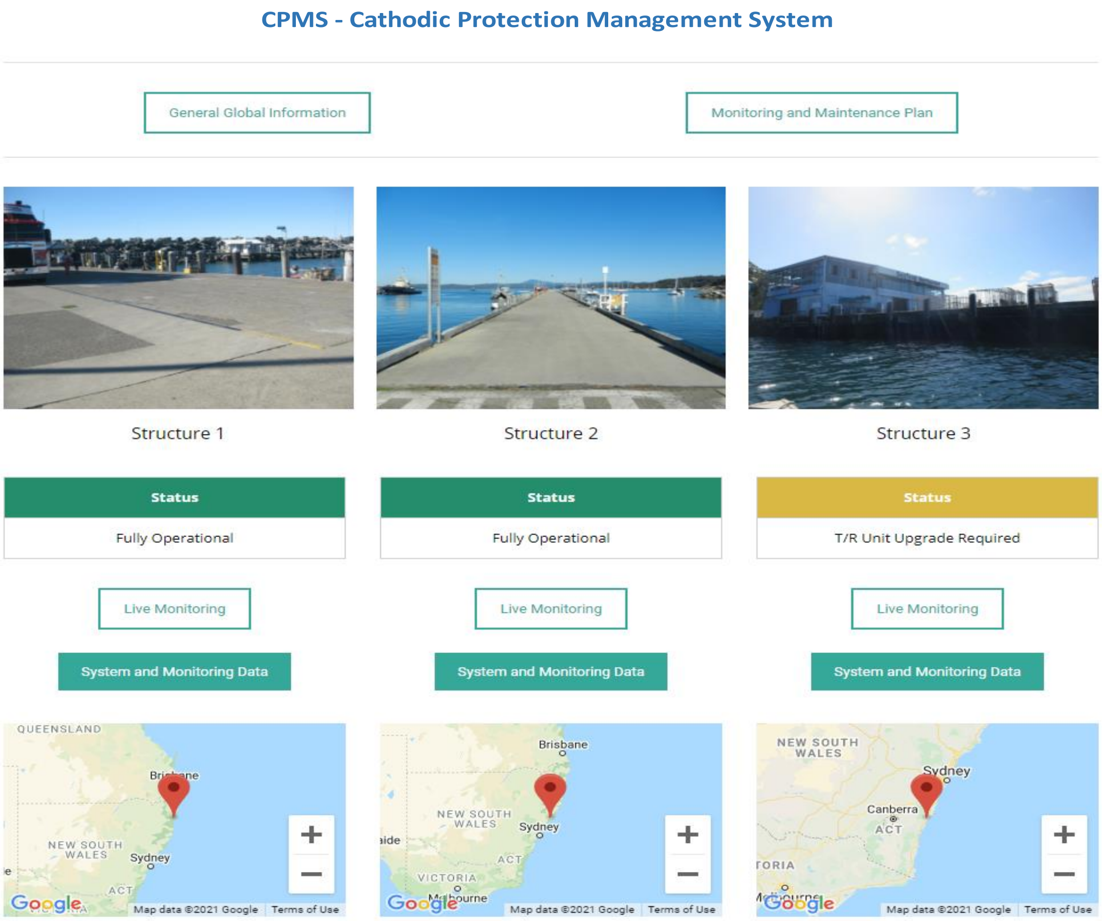

FIGURE 1: AN EXAMPLE OF MAIN PAGE OF CPMS. THIS PAGE IS SETUP FOR 3 CP-PROTECTED STRUCTURES WHICH ARE DISPLAYED SIDE-BY-SIDE. THE SYSTEM STATUS BAR FOR STRUCTURE 1 NOTIFIES THE USER OF CURRENT MAINTENANCE.

The monitoring of performance of ICCP installations is based on the relevant standard for cathodic protection of steel in concrete, Australian Standard AS 2832.5-2008 (R2018). The standard sets out the criteria used for system testing and adjustment of CP current. For the main decay criterion, the monitoring procedure involves measuring the difference in potential between each reference electrode and the reinforcing steel immediately after switching OFF the cathodic protection current, and again after 24 / 72 hours after switching OFF the current.

In Figure 2, a typical program is displayed for the monitoring of sixteen ICCP systems and ten galvanic and hybrid anode systems. The monitoring process is managed using CPMS with all data presented electronically to asset owners. The type of systems included in CPMS are full remote monitoring and control systems, systems with remote connectivity for functional check only, manually operated ICCP systems with requirements for site testing attendance for functional checks, and remote monitoring and galvanic and hybrid systems that require site attendance for testing.

Proposed Testing Program for 36 months:

2023												2024												2025											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
	PR			FC			PR			FC			PR			FC			PR			FC			PR			FC			PR			FC	
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						
					SR												SR												SR						

FIGURE 2: A 3-YEAR MONITORING PROGRAM FOR 26 STRUCTURES. THE PROGRAM DETAILS THE FREQUENCY OF TESTING INCLUDING CP SYSTEM FUNCTIONAL CHECKS, PERFORMANCE TESTING AND SYSTEM REVIEWS FOR EACH INSTALLATION.

6. INNOVATIONS OF CPMS

The recent innovations with this CP management system have delivered the following advancements for asset owners:

- Improvements in reliability – System verification tasks can be carried out with only an internet connection. There is no need for special modems or software from the manufacturer to be installed on asset manager's computer.
- Interchangeable and non-proprietary components inside the control system – While the advantages of remote monitoring and control are essential for optimal system adjustment and full assurance of continuity of cathodic protection current delivery, this function has in the past been overshadowed by frequent failures and high costs to maintain systems with complex proprietary software and hardware.
- The latest advancements in design have been based on using heavy duty, low heat and interchangeable components for cathodic protection system control units. The interchangeability of components using modular design assembly has made the entire process of maintaining and upgrading ICCP systems simpler and more cost efficient.
- Increased accuracy for decay testing – The majority of impressed current cathodic protection systems in Australia are designed to protect the tidal and splash zones of concrete infrastructure. In these environmental conditions, with the daily wetting and drying of concrete, the tidal variations greatly impact on the performance of the cathodic protection system. This can be assessed in the monitoring and decay testing data. During decay testing, switching OFF the current causes the reinforcing steel to become depolarised. The potential relative to the reference electrode becomes less negative, therefore, these measurements (Instant OFF and 24h/72h OFF) provide an indication of the extent to which the CP system is functioning in accordance to the applicable standards. In order to perform the test correctly, it is essential that the difference of potential over the test period is measured under exactly the same tidal conditions and in most cases over 24 hours and 72 hours period. It is important to note that when the absolute potential or/and absolute passive criteria of AS 2832.5 -2018 are used for system assessment, drift in potential cannot be detected and unless the references are calibrated, these criteria should not be used for system adjustment and assessment.

- Remote monitoring access for system testing, in conjunction with the data related to the daily tidal levels for a particular structure, allow for selection of the exact timing to switch OFF the system and to retrieve the initial Instant OFF data and subsequent 24 or 72 hour data at the correct tidal levels.
- On-demand remote system verification and fewer site visits to the control system - Following CP system testing and adjustment as applicable (based on the applicable standard), additional verifications of current and voltage can be performed at a later time to assess whether the level of current adjustment was sufficient to deliver the optimum corrosion protection. The reliable access to system data over the testing period and subsequent verification of data after current adjustment cannot be achieved by work personnel performing this test manually on-site as physical attendance is required every time for the testing period. The reliable access to remote data contributes substantially to accurate system testing and consequently to improve corrosion protection of the structure.
- CPMS and solar powered CP systems for remote locations - The use of solar power for impressed current cathodic protection systems is not a new concept. The technology can eliminate the need for permanent 230 VAC power supply and can rely on solar power to deliver CP current to the structure.
- The connection of CPMS to solar powered sites (often in remote locations where mains power is unavailable) can allow for verification of CP system operation at all times. Recent developments in high precision digital control buck converter technology, lithium-ion battery technology, improved phone regional coverage, and increased efficiency of modems and communications components have led to the development of a reliable monitoring capability for solar powered ICCP systems.

7. Summary

A significant challenge associated with impressed current cathodic protection is the ongoing maintenance of operating systems, which can often extend over a system's design life of 30 years or more and the ability for successive maintenance managers to access all of the relevant data to operate their ICCP systems over that period.

Cathodic Protection Management System (CPMS) was initially designed as an internet-based monitoring and maintenance tool for ICCP systems. The continual development of the platform increased the reliability and ease of system verification checks using more reliable modem and communications technology. The latest capability of CPMS allows for remote system testing and adjustment of current as per the applicable Australian Standard for cathodic protection of steel in concrete.

The overall benefit has been clearer and more efficient monitoring and maintenance of impressed current cathodic protection (ICCP) systems. The CPMS platform has effectively addressed some of the perceived shortcomings associated with monitoring and maintenance planning for ICCP systems. This management tool and its associated benefits have generally promoted the adoption of impressed current cathodic protection technology for reinforced concrete assets in marine environments.

8. References

1. Lambert, P., 2002, Reinforced Concrete – History, Properties & Durability, Corrosion Prevention Association, Surrey UK
2. NACE International, Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures. 2007 SP0290-2007 (formerly RP0290)]; Available from: https://store.nace.org/sp0290-2007.
3. The European International Standard, Cathodic Protection of Steel in Concrete. 2016 ISO 12696:2016]; Available from: https://www.iso.org/obp/ui/#iso:std:iso:12696:ed-1:v1:en.
4. Standards Australia, AS 2832.5 – 2008, Cathodic Protection of Metals, Part 5: Steel in Concrete Structures. 2008.

5. Chess, P., 2019, Cathodic Protection for Reinforced Concrete Structures, CRC Press Taylor & Francis Group, Boca Raton, Fl, USA
6. Cheytani, S., Data Analysis of the Long-Term Residual Effect of Cathodic Protection on Reinforced Concrete Structures; Available from: File:///C:/Users/Samir%20Cheytani/Downloads/public%20version%20(1).pdf

AUTHOR DETAILS

	Martin Cheytani has a PhD from the UNSW, and he is the technical manager of Remedial Technology Pty Ltd. Remedial Technology is a consultancy company specialising in the corrosion protection of reinforced concrete infrastructure assets in Australia. The author's main expertise is in the monitoring and maintenance of impressed current cathodic protection systems. The author's research work at the University of New South Wales involved the mitigation of grout acidification problems associated with impressed current cathodic protection systems and the impact of concrete resistivity on the performance of cathodic protection systems.
	Samir Cheytani has comprehensive experience in the condition assessment of concrete structures affected by steel reinforcement corrosion. He is involved in investigative site work including concrete testing, electrochemical testing, data analysis and the development of rehabilitation solutions for reinforced concrete structures. Samir has completed a Bachelor of Property Economics degree in 2005 from the University of Technology, Sydney (UTS), and a Master of Philosophy in Material Science and Engineering in 2020 from the University of New South Wales (UNSW).
	Atef Cheaitani is the Principal and Managing Director of Remedial Technology, a consultancy company specialising in the corrosion protection of reinforced concrete infrastructure assets in Australia. Atef's expertise is in the development of various rehabilitation solutions including the application of electrochemical protection systems and the design and maintenance of impressed current cathodic protection systems for reinforced concrete structures in marine environments.