NEW INNOVATIONS IN ICCP CURRENT DELIVERY TO CONCRETE STRUCTURES

A. Cheaitani[1], M. Cheytani[2] and T. Laurila[3]
[1&2]Remedial Technology Pty Ltd, Sydney, Australia
[3]Savcor Oy

SUMMARY: Impressed current cathodic protection (ICCP) is a proven technology for the long-term corrosion protection of reinforced concrete structures in marine environments. While the application of this technology can be highly effective in stopping chloride-induced corrosion, the ongoing monitoring and maintenance requirements of these systems, in some cases, can become costly and complicated.

The perceived shortcomings of ICCP has led to increased interest in recent years in the use of galvanic and hybrid anode systems, mainly because they require no permanent power supply units. While galvanic and hybrid anode systems are efficient in specific circumstances, in applications such as in high resistivity concrete, or structures with advanced chloride-induced corrosion, these types of systems fall short in terms of corrosion protection, are not proven, and do not meet applicable cathodic protection standards and operational life expectations.

The development of new and innovative methods of reliable current delivery for ICCP systems in conjunction with simplifications in the design, installation and monitoring of these systems can substantially reduce the complexity and the cost of ongoing maintenance and ensure that less effective galvanic based systems are not selected for the long term maintenance of infrastructure assets.

The most recent research in the area of power supply unit manufacturing has led to the development of simplistic, heavy-duty, solar powered, DC power supply units for current delivery to small or medium sized ICCP systems.

This new innovative method of current delivery, using simple components, eliminates the complexity and maintenance issues which have been associated with traditional ICCP systems.

This paper will present information related to Solar ICCP technology and new developments which have emerged from long-term experience and research work related to the simplification in the design, installation and monitoring of ICCP systems.

Keywords: corrosion, cathodic, chloride, solar, concrete, resistivity, monitoring

1. INTRODUCTION

Impressed current cathodic protection (ICCP) for reinforced concrete structures is a proven technology which can provide long-term corrosion protection to marine structures. This technology has been installed on a large number of structures in Australia over the past 35 years and has until recently been the technology of choice for the long-term rehabilitation of major wharves and bridges in Australia suffering from chloride-induced corrosion.

With the large number of ICCP systems installed in Australia over the past years, there have been some issues associated with ICCP monitoring and maintenance costs. These issues have mostly been related to complexity and poor reliability of some power supply units and control systems, durability issues associated with grout acidification from ribbon anode strips located in tidal and splash zones, and shortfalls in establishing simple monitoring and maintenance programs for these systems. In spite of these issues, it is generally accepted that a well-designed and monitored ICCP system can deliver optimum corrosion protection to a concrete structure and meet the protection criteria in accordance with the applicable standards.

However, in recent years, some assets owners have been inclined to select galvanic anode systems for the corrosion protection of their assets. One of the primary reasons has been the perception that galvanic anode systems offer the same level of corrosion protection to structures as ICCP, while eliminating the requirements for ongoing monitoring and maintenance work over the life of the asset.

This paper will present the basic theory of cathodic protection, highlight the advantages and disadvantages of ICCP and galvanic anode systems and will present information related to Solar ICCP technology and new developments which have emerged from long-term experience and research work related to the simplification in the design, installation and monitoring of ICCP systems.

2. CATHODIC PROTECTION SYSTEMS

When steel corrodes in concrete, the electrochemical process is comparable to that of a battery. In a battery, electrons which are generated because two dissimilar metals are exposed to an acidic solution (paste or gel in conventional batteries) which 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’.

When steel reinforcement begins to corrode in concrete, a small area becomes the positive pole (anode) and another much larger area becomes the negative pole (cathode). The corrosion current flows out of the steel at the anode (the corroding part), passes through the concrete and to 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 oxide.

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.

In concrete, the corrosion circuit is buried in the structure and the electrical current running through the concrete cannot easily be disconnected. Cathodic protection technology is based on stopping the current from running through the concrete by providing a new current from an external source via an external anode in contact with 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 reinforcement becomes the negative pole or cathode, and hence the name ‘cathodic protection’.

For concrete structures, there are two types of cathodic protection systems; galvanic anode systems and impressed current cathodic protection systems (ICCP).

2.1 Galvanic anode systems

Galvanic anode systems are currently an area of substantial growth. This technology is becoming increasingly attractive because of its simplicity and low monitoring and maintenance requirements. The anode which is normally made from a metal such as zinc, is connected to the reinforcing steel and the potential difference between the zinc and the steel causes a small protection current to flow from the zinc to the steel.

Galvanic anodes in concrete are usually supplied with a proprietary backfill which provides space for the products of anodic dissolution. As the failure to provide a conductive bridge between an oxidised anode and concrete will effectively stop the protection current, most of the recent innovation and research in galvanic anode technology has been associated with the backfill material. Hybrid anode systems differ from the purely galvanic systems. The hybrid treatment consists of applying a temporary impressed current followed by permanent galvanic protection. The principle of this system is that during the initial impressed current phase, active pits are realkalised and this arrests active corrosion and returns the reinforcing steel to a passive state. Following the application of impressed current for a predetermined period of time, the passivity of the steel is then maintained by the galvanic anode system.

For many years, galvanic anode systems had been installed in conjunction with concrete patch repairs to reduce the occurrence of the incipient anode effect. Normally in such applications, no permanent monitoring system is incorporated and there is no reliable data about the level of the long-term effectiveness or benefit from the installation of these anodes. The installation of galvanic anodes had been traditionally viewed as an additional and low-cost measure to prolong the life of patch repair work.

In recent years, galvanic based anode systems including hybrid anode systems have been installed in various wharves and bridges in Australia on the perception that they offer long-term corrosion protection for all structures regardless of the chloride level in concrete and the level of corrosion activity.

Based on the authors experience and the performance data from various galvanic systems (1), for structures with a high level of chloride contamination, high corrosion activity, and in some cases relatively high resistivity, the level of corrosion protection that can be delivered by galvanic based systems is limited and the protection criteria (in accordance to the applicable standards) cannot be achieved.

2.2 Impressed current cathodic protection systems

Impressed current cathodic protection (ICCP) is a well-established technology for the corrosion protection of reinforced concrete structures. All aspects related to the design, installation, monitoring and protection criteria for ICCP systems are documented in global standards such as the NACE Standard SP 2290-2007 (1), International Standard ISO 12696:2012 (2) and the Australian Standard AS 2832.5 – 2008 (3).

While this technology has been available and widely used in Australia for over three decades, there have been some shortcomings which have emerged associated with its application. This paper will detail the areas for improvement and the newest innovations related to design and installation of ICCP systems.

2.3 Areas for improvement of ICCP systems

The key areas of improvement for ICCP systems include the development of simple system designs, heavy-duty components, and systems which are simple to monitor and maintain over their design life. In order to achieve these objectives, based on our extensive experience with the installation and monitoring of a large number of ICCP systems, there are various key areas which have been identified related to control systems design and construction.

2.3.1 Conventional power supply

Various types of control systems have been installed in Australia in recent years. All of these control systems require 240VAC power supply. These control systems range from manually operated systems, to highly advanced systems with full remote monitoring and control capabilities including remote facilities for depolarisation testing and various levels of alarm functionality.

The capacity of an ICCP system to deliver continuous cathodic protection current to a structure is the key and most important requirement of the control system. It is the author’s opinion that after one year following system commissioning, minimal and less frequent CP system adjustments are normally required to maintain optimum system operation and compliance with standards.

The author’s experience is that regular functional checks of current delivery, in conjunction with half-yearly/yearly testing and adjustment of the system (including an inspection of the structure), is sufficient for the adequate long-term monitoring and maintenance of the ICCP system.

Failure to select a suitable control system for a particular structure may result in the following:

- Problems with delivering cathodic protection current to the structure, and thus reducing the capability of the system to provide adequate corrosion protection.
- Frequent parts replacement and associated repair work.
- Excessive ongoing costs for monitoring and maintenance of the system.

Assessing the need and the benefit of control systems against the complexity of maintaining and operating them must be carried out for each individual structure. Advanced control systems systems may be suitable for large and complex ICCP installations located in areas where they can be easily serviced, and for structures where more frequent monitoring and control is required such as prestressed steel concrete structures. However, for relatively basic and simple ICCP installations or installations in remote locations, it is likely that such systems will add no value in efficiency for a long-term and cost-effective maintenance program.

The primary and most essential function of a control system is to provide continual delivery of current to the structure to ensure protection at all times. It is the author's opinion that a CP system should have simple functions which can allow the asset owner's maintenance staff to easily carry out all functional checks without the need for any specific software knowledge.

It is the author's experience that an optimum control unit for a CP system should consist of the following components:

- Reliable, modular and heavy-duty components.
- Standalone manual operation.
- Local display for current and voltage for each circuit.
- Function for instant OFF current interruption for each circuit.
- A data logging facility (typically required for large systems only).
- Reliable web-based remote monitoring for functional checks only. This is highly recommended for installations in remote locations where this function cannot be carried out regularly by the asset owner's maintenance staff.

2.3.2 Solar ICCP

The concept of using solar power for impressed current cathodic protection systems is not new. However, recent developments in high precision digital control buck converter technology, lithium iron battery technology, improved efficiency and reduced cost of PV systems, elimination of the need for power inverters, high reliability of data acquisition and integration into IoT applications has led to the development of reliable Solar ICCP systems which are capable of delivering the required cathodic protection current suitable for small and medium sized ICCP systems.

Based on our experience with monitoring ICCP systems, the key problems associated with conventional systems are:

- The requirement to ensure the permanent delivery of 240VAC power supply to the unit.
- The complexity of securing and successfully replacing spare parts for older systems.
- Specific software knowledge to operate some systems.
- The complexity of upgrading existing modems for compatibility with the latest network requirements.

The adoption of Solar ICCP technology eliminates many of these problems and the technology offers basic and robust components which use solar power to deliver the corrosion protection to concrete structures, and above all, can meet the protection criteria in accordance to the applicable standards.

Further, advances in the area of routers and communications offer the option to incorporate reliable remote monitoring for Solar ICCP systems to ensure that they are functional at all times and are delivering the required corrosion protection with minimal maintenance.

2.3.3 Grout acidification

In many ICCP installations where ribbon anode is used in tidal zones, there is often the occurrence of acidification problems at the anode locations. In the majority of cases, water ingress to the anode due to poor anode encapsulation detail has been the main contributing factor leading to acidification.

Recent research (5) has confirmed that the anode embedment methods currently in use by the industry in Australia, often combined with sub-par workmanship detail, can allow water ingress to the ribbon anode which can lead to grout acidification. The research also established that the application of a cementitious waterproofing coating (which stops or minimises water ingress to the ribbon anode), and/or an alternative and superior encapsulation methods can limit the occurrence of grout acidification problems in operational ICCP installations.

Figures 1 and 2 below show a cross section of a reinforced concrete element protected by four ribbon anode strips and subjected to accelerated CP application equivalent to fifteen (15) years of system operation at 20 mA/m² of steel surface. Figure 1 shows the impact of water ingress and grout acidification for two anodes, and Figure 2 indicates that proper encapsulation of the anode (preventing water ingress) can eliminate grout acidification problems caused by external water ingress.

Figure 1. Grout acidification evident at anode locations

Figure 2. No water ingress to anode locations

2.3.4 System zoning

In theory, designing ICCP systems with smaller zones (circuits) provides a higher level of control of the cathodic protection current in various sections of the structure. However, for larger installations, the use of smaller circuits also carries the requirement for more cabling, more reference electrodes and a larger number of power supply units for the system.

Recently, the authors of this paper were involved in the refurbishment work of a relatively large ICCP installation at Wharves 4 & 5 at Port of Brisbane (6). As part of the refurbishment work, 13 control units incorporating 172 separate power supply units were moved from underneath the wharf to locations above the wharf. The original system design of this ICCP installation included 172 circuits. The new control system (following refurbishment) included only 48 circuits. The substantial reduction in the number of zones (circuits) was achieved by combining smaller circuits which have the same exposure conditions and CP current requirements.

Following system re-commissioning, a comparison of CP performance data before and after the reduction in circuits indicated that the larger cathodic protection zones offered the same level of corrosion protection and adequate current distribution to the embedded steel. The reduction in the number of circuits had a major impact on reducing the quantity of cables, conduit, power supply units and consequently the overall cost of ICCP system installation. Providing that the embedded reference electrodes are placed correctly (as recommended by the applicable standards), larger circuits can be used for ICCP systems without compromising corrosion protection and current distribution.

2.3.5 Elimination of junction boxes

Junction boxes which are installed in areas subject to water exposure are normally specified with Ingress Protection (IP) suitable for such exposure. It is the author's experience that regardless of the IP protection of these enclosure, such protection is likely to be compromised during the design life of the CP system when these enclosures are installed in areas susceptible to water exposure. For junction boxes installed in such areas, the following causes, or a combination of these causes, can result in failure:

- Movement in the structure causing physical damage to the junction boxes and conduits and thus allowing water ingress.
- Failure of the rubber seal cover of the junction boxes.
- Failure of the sealant applied around the conduit entries.
- Damage to cables/terminal connections in the junction box.

With the aim of reducing repair and maintenance requirements, eliminating junction boxes altogether in areas where the junction boxes will be susceptible to water ingress, or alternatively permanently sealing the junction boxes with epoxy material or other suitable products, should be considered in the design stage of the ICCP system.

2.3.6 Current density

The typical design current density for existing reinforced concrete structures is 20 mA/m² of steel surface. Based on data retrieved from a large number of operating ICCP systems, in many cases the actual operating current density is in the range of 5 – 15 mA/m² of steel surface.

The current density required to achieve protection and meet the criteria as defined in the applicable standards is related to chloride content, concrete resistivity, the level of corrosion activity, exposure conditions and steel density. The only possible method to determine the required current density is to perform a current injection test at one or several locations of the structure using a temporary power supply unit. The results from the current injection test can be obtained immediately by measuring the potential shift of the embedded steel after a short period of time from impressing CP current. The outcome from this test may, in some cases, reduce the design current density from the default 20 mA/m² of steel surface to a lower figure resulting in a major reduction of anode requirement, reduction of power supply unit capacity and consequently major cost reductions for the installation of the ICCP system.

2.3.7 Monitoring of ICCP systems

The main challenge associated with ICCP systems is related to ongoing maintenance, which can often extend over a system's design life of 30 years or more, and the ability for successive maintenance managers and their consultants to access all of the relevant data to operate their systems over that period. This data includes the original specifications, original drawings, consultant's reports, maintenance records and performance records…etc. In addition to this, having a simplistic, reliable and cost-effective system for managing multiple assets is one of the challenges for asset managers for the long-term management of their structures and ICCP systems.

Cathodic Protection Management System (CPMS) is an advanced management tool for the efficient monitoring and maintenance of cathodic protection (CP) systems (7). This is a web-based management system which provides a simple and reliable platform for managing the maintenance and monitoring requirements of multiple ICCP systems. Further, CPMS offers a live monitoring portal which allows transmission of real time data from the cathodic protection system.

CPMS features for asset owners include:

- Simple and secure access for approved users through a password protected website.
- Online yearly maintenance programs for all structures showing up-to-date work progress and recommendations for future maintenance work for planning and budgeting purposes.
- All historical CP system data is consolidated onto one platform. This allows full transparency related to the status of the systems, information sharing and easy transition of responsibilities between successive asset managers.

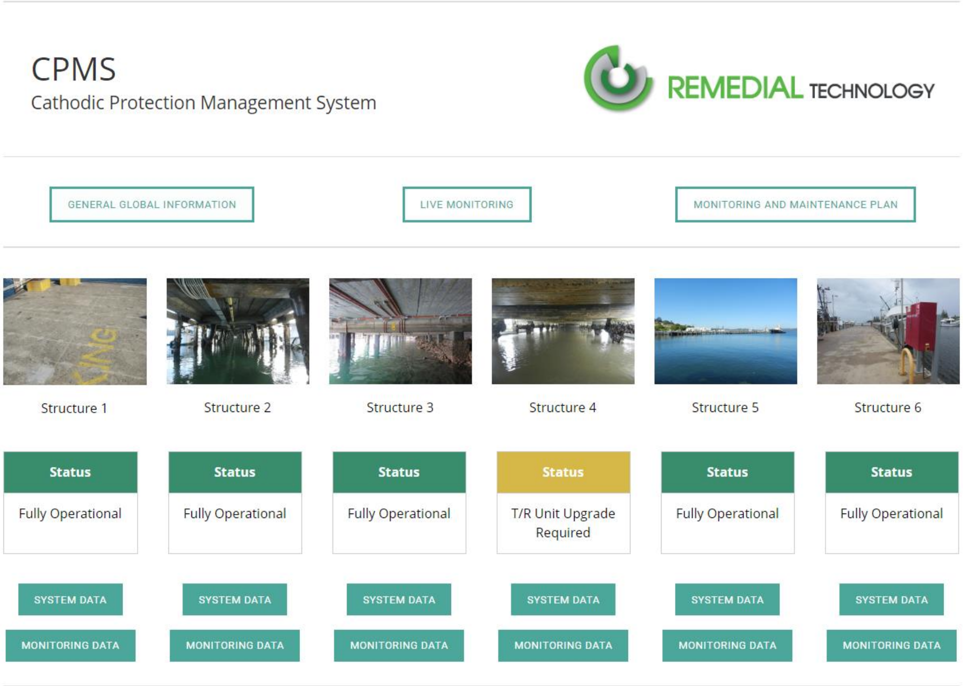

Figure 3. CPMS main page showing six CP-protected structures

3. CONCLUSIONS

Cathodic protection for steel in concrete can be effectively utilised to provide corrosion protection to structures suffering from chloride-induced corrosion. However, it is the role of engineers and consultants operating in the field of infrastructure rehabilitation to provide the correct advice to assets owners with respect to selecting the optimum system for the long-term protection of their assets.

There is no doubt that impressed current cathodic protection systems have higher capacity for operation in high resistivity concrete and can provide protection in aggressive environments and for structures with high corrosion activity. The primary selection criteria for the type of cathodic protection system for asset protection should be the ability of the system to meet the protection criteria in accordance to the Australian Standard AS 2832.5 – 2008.

Various aspects of cathodic protection of steel in concrete structures are detailed in international and Australian standards and are available to assist owners, consulting engineers and contractors to correctly design, install, test, commission, monitor and maintain impressed current cathodic protection systems.

The proper design of these systems and the selection of heavy duty, reliable components and control systems, combined with the establishment of an efficient maintenance and monitoring program for the structure will ensure that sound maintenance practices become routine and permanent corrosion protection is achieved for the asset.

The failure to design simple and heavy duty ICCP systems for the corrosion protection of reinforced concrete structures will open the door for the preference of less effective galvanic anode systems which cannot achieve the applicable protection criteria and are more costly and less effective for the long-term corrosion protection of infrastructure assets.

New and innovative methods of current delivery such as solar technology and robust components can reduce the complexity of ongoing maintenance issues (which are commonly associated with traditional ICCP systems) and make viable the use of renewable energy for the preservation of assets.

These new developments in impressed current cathodic protection technology offer a true opportunity to deliver the optimum corrosion protection to infrastructure assets in marine environments, reduce ongoing maintenance costs, and increase the longevity and value of these assets.

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5. AUTHOR’S DETAILS

Atef Cheaitani is the Managing Director of Remedial Technology, an engineering consultancy company, specialising in corrosion protection solutions for infrastructure assets in Australia. Atef has a Master of science in structural engineering and a Master of science in Civil Engineering. Atef’s main expertise is in the assessment and development of rehabilitation solutions for reinforced concrete structures. Atef has pioneered the introduction of cathodic prevention technology to Australia, China and India and has been involved in the development of various patented technologies associated with impressed current cathodic protection of concrete structures.

Martin Cheytani completed a Bachelor of Construction Project Management (BCPM) in 2014 from the University of Technology, Sydney (UTS), a Master of Philosophy (MPhil) in Material Science and Engineering in 2017 from the University of New South Wales (UNSW), and is currently undertaking a PhD at the University of New South Wales. Martin’s research work is in grout acidification and the impact of concrete resistivity on electrochemical protection systems. Martin is the Technical Manager of Remedial Technology.

Timo Laurila is the Vice President of Savcor OY in Finland. Timo has a master’s degree in Material Science from the university of Tampere, Finland. In the past 30 years, Timo has been involved in R&D work related to cathodic and anodic protection systems, structural health monitoring technology and corrosion rate monitoring for concrete and steel structures. Timo has been involved in the design and installation of major cathodic and anodic protection systems in Finland, Scandinavia, Russia and North-America.