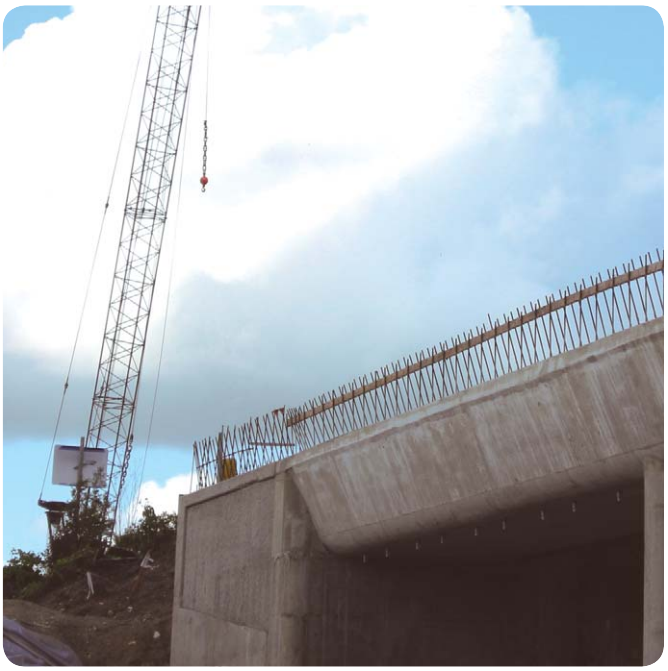
Cathodic Protection of Steel in Concrete Using LXI

Application Note



Agilent Technologies

Concrete is a solid and long-lasting substance, but under certain circumstances, it can lose its durability. One possible issue is corrosion of the steel reinforcement built into concrete structures. The life span of these structures could be reduced dramatically with certain environmental conditions (deicing salt etc). This could be bad news for the people who maintain a highway bridge or parking garage. Cathodic protection is a remarkable technique that can substantially extend the life of a building structure by impeding corrosion.

Cathodic protection—an introduction

Corrosion is an electrochemical process—it involves electrical current. Let's take, for example, a steel structure, like a pipe, buried in humid earth. Minor differences in material composition and surface structure will cause small electrical potentials to develop, similar to a thermocouple. The resulting current that flows through the surrounding earth to areas of the structure with lower potential will cause the metal to dissolve at the anode (where ions leave the material), just like in a galvanic process.

In principle, the steel reinforcement in concrete structures, e.g. bridges and parking decks, is subject to these same processes. However, the highly alkaline nature of modern concrete mixes passivates the steel and protects it from corrosion.

The trouble starts when the concrete structures are subject to substances like deicing salt over prolonged periods of time which is an issue with bridges and parking facilities in colder climates. Over time, the chloride will permeate the concrete structure and weaken its alkalinity, and, when it reaches the steel reinforcement, causes corrosion.

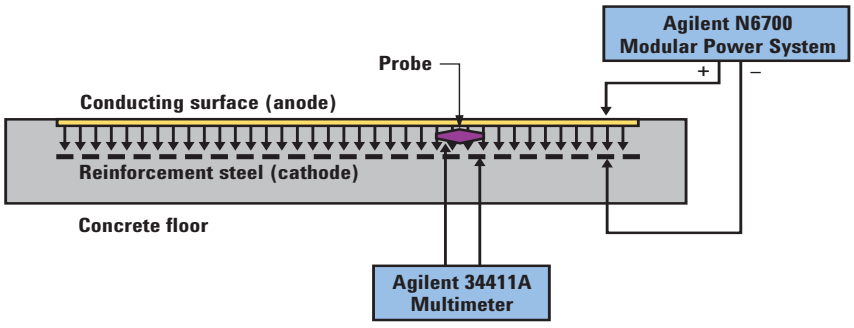
The conventional method of repair is to remove and replace the chloride-affected material before it reaches or weakens the steel reinforcement—undoubtedly a very expensive measure.

Cathodic protection is a modern alternative. It does not require the replacement of chloride-affected material. Pioneered in the USA and the UK in the second half of the 20th century, it has become a well understood and accepted method for corrosion protection. Let's have a look at how it works.

With cathodic protection, an electrical field is applied to the concrete structure with the steel reinforcement being used as the cathode (see Figure 1). The resulting current will flow from the anode to the steel reinforcement and make it impossible for any current to flow in the opposite direction, effectively protecting the steel from corrosion.

An important aspect about cathodic protection is that the efficiency of the system can be verified and monitored using voltage probes and other sensors placed in the concrete.

Figure 1. Cathodic protection (example)



- An electrical field is generated between a conducting surface layer and the steel reinforcement using the Agilent N6700 Modular Power System.
- The electrical field enforces a current flowing to the reinforcement steel, impeding corrosion of the reinforcement.
- Probes placed at different locations in the concrete allow verification of proper function and correct electrical settings.
- The probe voltages are measured continuously using the Agilent 34980A or 34411A/L4421A combination.

Solution overview

SUSPA-DSI, a major construction company producing and supplying high quality products for mining and construction applications, especially for prefabricated prestressing elements, offers also a range of services and solutions in the area of cathodic protection. This application note describes some aspects of their solution design, based on Agilent LXI components.

When employing cathodic protection in a building, the structure is typically divided in separate sections or zones of 100 square meters or less. Consequently, the DC power supplies and measurement probes are distributed across the whole building to be protected. Modularity and flexibility are important prerequisites for any practical solution, because they allow the basic solution to be scaled to buildings of different size and complexity.

SUSPA-DSI uses the following Agilent LXI components in their solutions.

Figure 2. Major components of the solution designed by SUSPA-DSI

N6700 Modular Power System

- Modular system design with 4 slots in 1U
- Up to 300W per module
- Choice of 20 different modules

34411A Digital Multimeter

- 6.5 digit resolution
- Up to 50,000 readings/s, memory for 1M readings
- Analog level and pre/post triggering

34980A Switch/Measure Unit

- 8-slot mainframe with optional 6.5 digit multimeter
- Choice of 19 plug-in modules, including: switching (DC to 20GHz), digital I/O, D/A converters, multifunction, breadboard

L4400 Series LXI Modules

- Compact format (half rack width, 1U)
- Choice of modules, including: switching, digital I/O, D/A converters, multifunction

The Agilent N6700 Modular Power System (see also fig. 2) is a modular and compact (1U) system power supply mainframe—it can be fitted with up to 4 independent power modules. A wide range of such modules is available, with different output power, voltage and functionality.

The Agilent 34980A Switch/Measure Unit is a modular switching mainframe—it accepts up to 8 switch cards and also features a high-precision (6.5 digit) digital multimeter. Different switching densities and technologies are available, including armature relays, reed relays and high-speed FET switches. The multimeter can measure, among other parameters, current, voltage and temperature. In addition to measurement and switching, the 34980A can be equipped with additional cards for digital or analog stimulus.

The Agilent 34411A digital multimeter and L4400 series switch modules are similar in concept to the integrated solution in the 34980A—however, for smaller channel counts, they offer similar measurement and switching functionalities in an even more compact format (half rack width and 2U/1U, respectively). This combination is used in truly large installations where the measurement capability is distributed across the building.

All of the above are intelligent instruments. For example, the 34980A can do its measurement job for days and weeks without interaction with the system controller. Once the measurement channels (scan list) and frequency of measurement have been set, the instrument is fully self-contained and will continuously log measurement results to its internal memory of 500,000 readings. This is a key advantage, especially with off-site installations such as bridges.

Measurements

The concrete mix is alkaline in nature and plays the role of an electrolyte. The different materials of steel reinforcement and measurement electrodes will work like a battery. As a result an electrical potential will develop between the two, similar to a battery—even without an external electrical field being applied. This initial electrical potential is among the first measurements that are done in cathodic protection after the installation of the system. The measured voltage is usually around -900 mV. The presence of this negative voltage indicates that the electrodes and, in general, the system wiring is working properly.

After the basic verification of the system, cathodic protection itself begins. The power supplies are turned on and the electrical fields and currents are applied to the individual protection zones. As a result, the concrete will begin to polarize, and the voltage levels present on the electrodes will begin to shift to a higher, negative potential. The applied current is either programmed to a predefined level or increased steadily until the electrode's potential has shifted by a certain voltage difference. This process of polarization usually takes a number of days or weeks. During this period, the electrode potential is measured constantly.

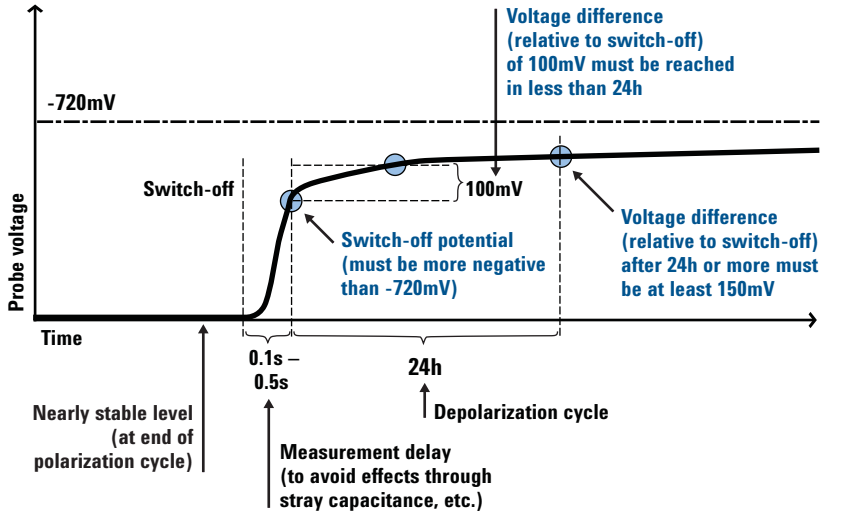
Once the polarization has taken place, the proper function of the system is tested again. For this purpose, the power supplies are switched off in order to be able to monitor the depolarization of the concrete. Shortly after switching off the supplies (there's a little waiting time in order to avoid effects through stray capacitance), the "switch off potential" is measured. Then, the voltage shift is monitored over the course of several hours. The voltage shift, relative to the "switch off potential" needs to satisfy a number of criteria.

If the conditions mentioned above are not met properly, the strength of the electrical field is altered accordingly during the next polarization cycle.

A measurement system for this application needs to have the following characteristics:

- High input impedance. The above described measurements need to be taken while placing as little load as possible on the sensors.

Figure 3. Interpretation of measurement results (example)



- Stable measurements in the presence of relatively long cables and resulting noise. Integrating voltmeters have a clear advantage in such situations because random and power line induced noise can be filtered out quite effectively.
- Synchronization capability. As mentioned above, some measurements need to be taken right after switching off the power supplies. In other words, the power supply and multimeter need to be synchronized.

The 34410A/11A and 34980A are high-impedance, integrating voltmeters and feature the required inputs for external synchronization.

Remote Access

LXI components, by definition, use Ethernet for control. They can natively connect directly to any standard Ethernet LAN, be it a public network or corporate intranet. Only Ethernet offers that unique combination of attributes: high data rates (beyond 100 Mbytes/s with GbEthernet), unprecedented ease-of-use, tremendous flexibility with simultaneous communication and different protocols, stability and, finally, unrivaled fitness for distributed applications. Bridging large distances in distributed test applications doesn't get any easier than this!

Depending on the complexity of the installation, several options are available.

Many smaller installations are exclusively controlled remotely and no local system controller is required. This is enabled by the distributed intelligence in the individual instruments. When appropriate, a central controller accesses the remote site, downloads gathered measurement data and reconfigures the instruments if necessary.

More complex installations might include a local system controller with application software that monitors the whole network, gathers and analyzes measurement data, reconfigures the system as required and automatically generates alarms if operating parameters are out of predefined limits.

Independent of the availability of a local system controller, several options are available with regards to Ethernet connectivity of the installation site to the outside world.

In some situations, an existing, private (corporate) LAN can be used to network the system components. Connectivity to the corporate headquarter and branch offices is a given. Typically, the network is managed by full-time IT professionals. Security is a minor concern since the installation is within a trusted, well-controlled environment.

Remote buildings, however, are often connected via the public Internet, available in the form of DSL, cable or wireless IP services such as GPRS. In this case, security and access control deserve more attention. Rest assured, commercial off-the-shelf and inexpensive solutions such as Virtual Private Network (VPN) capable routers are available to enable secure, encrypted access even when the data is going through the public internet.

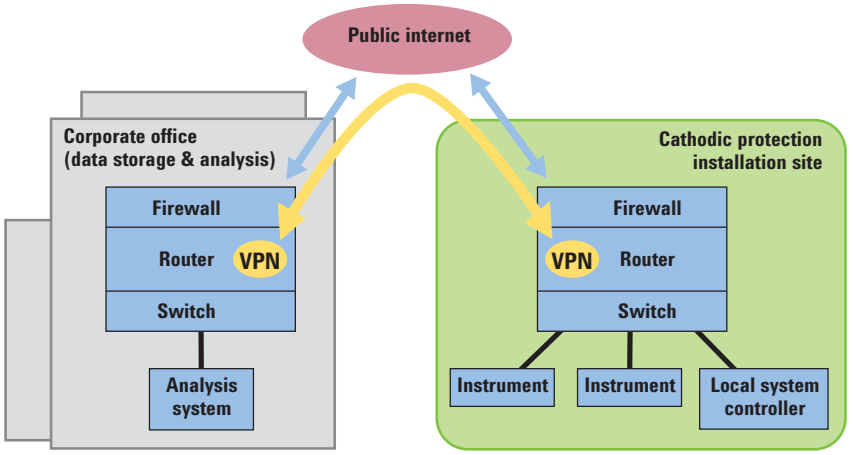
Ease-of-use

The Agilent LXI instruments described above also feature built-in web servers for monitoring and control via Ethernet and any standard web browser. All major instrument functionalities are accessible through the web server, greatly simplifying software development, system commissioning, troubleshooting and maintenance.

Summary

Worlds come together. With cathodic protection, electronic measurement instruments make their way into concrete buildings and new kinds of building services. The distributed and "off-site" nature of many buildings makes LXI an obvious choice for this application. Commercial, low-cost Ethernet services can be used to gain access and immediate control over the installation. But even more important, LXI instruments are self-contained, dependable units and lend themselves naturally to remote installations, in the lab or outside.

Figure 4. VPN and IPSec enable secure, encrypted data exchange via the public internet



About SUSPA-DSI

SUSPA-DSI, founded in 1953 in Augsburg, Germany, is a pioneer in prestressed concrete elements. In the early 1960s, the company led the industry move towards prefabricated concrete elements. In the 1970s, shipment of such elements was substantially simplified with the introduction of coiled tendons. SUSPA-DSI has been offering professional solutions and services for cathodic protection for many years.

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LXI

www.lxistandard.org
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