Remote Monitoring of Pipeline Cathodic Protection Systems

by Neil Summers

Abstract:

Cathodic protection (CP) systems are fundamental to pipeline integrity management and are widely used on transmission and (high or intermediate pressure) distribution pipelines in the gas, petrochemical and water sectors. To comply with regulatory safety standards, routine measurements of CP levels are required. Manual measurements, apart from their high cost, can only indicate problems after they have occurred, which can result in the pipeline being unprotected until the fault is discovered.

Remote monitoring of CP is a new development that automates the data collection process and provides operators with a proactive surveillance system. The system monitors the output voltage and current from transformer rectifiers in order to ensure that the correct level of CP is applied. The AC supply to the T/R is also monitored so that power outages can be reported immediately. At test stations along the pipeline the in situ CP levels (ON and OFF pipe-to-soil potentials) are monitored to ensure they remain within preset thresholds for DC and AC. Where a coupon is installed, it is also possible to monitor induced current from power lines or other electrical sources that may accelerate corrosion of the pipeline. Although mainly used for impressed current systems, remote monitoring is also being successfully extended to galvanic (anode-based) CP systems.

CP data is transmitted from the field units to an operational centre. The widely used communication methods are GSM/SMS in areas that have cell phone coverage and satellite in areas that do not. In either case data is transmitted automatically and wirelessly into a software package where it is displayed, archived and available for regulatory reporting. Alarms are generated automatically so that supervisory staff are constantly aware of the status of their CP system.

By identifying and reporting problems as they occur, remote monitoring ensures continuous, effective CP and so maintains or extends the operating lifetime of a pipeline. In Europe and the US it has been shown to be cost-effective, with a typical payback of less than 2 years. It increases safety by eliminating the requirement for measurements at roadside and inaccessible locations as well as eliminating electrical hazards to technicians. It also helps companies improve their environmental performance.

Introduction

Cathodic Protection Measurements

Pipeline operators protect against the long term effects of corrosion by applying high quality coatings to minimise the interaction between the pipe and the surrounding soil. However, defects can occur in the coating. A secondary method of protecting the pipe metal against corrosion is therefore required.

Corrosion is the electrochemical process that takes place when a metal is exposed to its environment. Corrosion normally occurs at the anode but not the cathode of the circuit. The principle of cathodic protection (CP) is to connect an external anode to the metal to be protected and to pass a positive DC current between them so that the metal becomes cathodic and does not corrode.

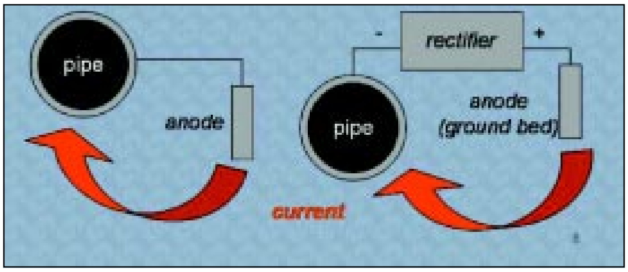


Figure 1: Types of cathodic protection system – galvanic (L) and impressed current (R)

All pipeline operators use CP extensively on their transmission pipelines. The big advantage of CP over other forms of corrosion treatment is that it is applied very simply by maintaining a DC circuit and its effectiveness can be monitored continuously. There are two main CP system types (Figure 1):

- In a **galvanic system** the DC current arises from the natural difference in potential between the metal of the external anode (typically Zn, Al or Mg) and that of the pipe (carbon steel), to which it is electrically connected. While the pipe is protected, the anode corrodes preferentially and is referred to as "sacrificial". Galvanic systems are easy to install, have low operating costs and minimal maintenance requirements. They do not need an external power supply and rarely interfere with foreign structures. However, they offer limited protection of large structures and are mainly used for localised CP applications.

- In an **impressed current system** an external DC power source (rectified AC) from a transformer is used to impress a current through an external anode bed (usually inert) onto the pipe, causing its surface to become cathodic. The high current output of this type of CP system is capable of protecting long lengths of pipeline economically. However, impressed current systems rely on a continuous AC power source as well as the operation of the transformer rectifier (T/R) that energises the system.

Cathodic protection is so important in protecting a pipeline that operators are required to take and report regular measurements of CP data, both of the levels of protection applied to the pipe (at source) and the *in situ* levels measured along the pipe itself. The level of CP that is applied, especially from an impressed current system, is important. Too little current will not protect the pipeline adequately. Excessive current can lead to material degradation and premature failure of the pipeline. In an impressed current system, measurements of voltage and current outputs at T/Rs must be within acceptable limits. It is also important to monitor that the AC supply is always present – a power failure immediately renders the CP system ineffective.

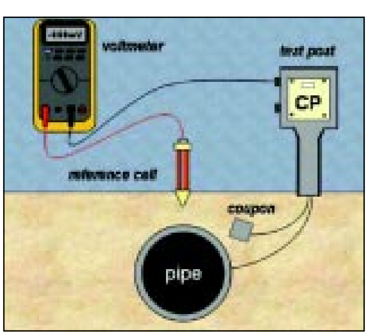


Figure 2: Manual CP measurements taken at a test post

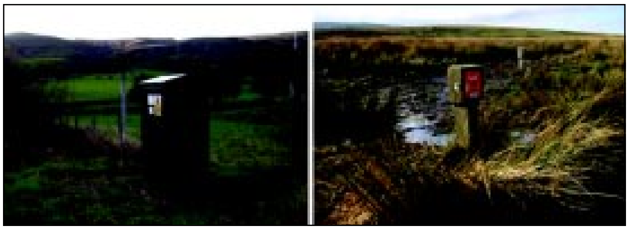
Figure 2 shows how, in a manual measurement, a multimeter is used to take spot readings of voltage potential at a test point that incorporates a physical connection to the pipe. Some or all of the measurements shown in Table A may be taken to confirm whether CP is being applied effectively to the pipeline. Of specific interest are:

- Drain points of T/Rs.
- CP low points (often mid-way between T/Rs or at the end of a pipeline).
- Pipe crossings or other sources of foreign pipe interference.
- Critical bonds and isolation joints.
- Downstream of compressor stations (elevated temperatures).
- Areas of susceptibility to AC (eg close to overhead power lines).

Table A: The main cathodic protection measurements

ON potential The potential of a pipeline at a given location (commonly known as the pipe-to-soil potential), resulting from the electrolytic reaction between the buried pipe and its surrounding soil (the electrolyte). The measurement is made while the CP system is energised.
Instant OFF potential The T/R output is briefly interrupted to produce a "true" pipe-tosoil potential, free from undesirable IR drop effects and before any appreciable depolarisation has occurred. This is a more meaningful measure of the protection afforded to the pipeline. If it is not possible to interrupt the T/R momentarily then an alternative approach is the use of a corrosion coupon (see below).
Coupon current A coupon is a representative sample of the pipeline material, buried close to the pipe so that it is subjected to the same environmental conditions and electrically connected to the pipeline. The instant OFF potential can be conveniently measured by interrupting the CP connection to the coupon. The measurement of current flow to/from the coupon can also be determined by measuring the voltage across a resistor (shunt). The surface area of the coupon allows the current density to be calculated.

The frequency of measurements at the various points can be varied according to local conditions but is generally in compliance with NACE guidelines – monthly or bi-monthly at T/Rs and anywhere from monthly to annually at test posts, depending on the performance of the CP system and external factors such as population density, interference and third party activity. Pipeline operators must provide their national regulatory body with evidence that their monitoring is adequate to demonstrate effective management of their CP systems. This is particularly important for pressurised pipelines containing gaseous or liquid hydrocarbons; however, CP can also be found on pipelines containing specialist chemicals, water and some gases, such as those used in the production of steel.



Figures 3a and 3b: Many CP T/Rs and test points are situated in remote locations where manual data collection is time-consuming

Historically, the CP data required for compliance and operational purposes has been gathered in the field manually. Pipeline operators have trained their technicians to carry out the various measurements and have implemented data management schemes to record and report the data. The scale of this activity has increased in proportion to the expansion of pipeline networks over many years. T/Rs are typically spaced at 15km intervals along a pipeline but are often difficult to access or in remote locations where vehicle access may not be possible. Transport time and cost are increasing and it is not uncommon for a technician to spend half a day travelling to a remote T/R or test point (Figure 3).

With pressure on all companies to maximise the productivity of their labour force, manual data gathering is increasingly seen as a poor utilisation of human resources.

CP Monitoring Requirements

In the past various attempts were made to implement remote monitoring but the cost of the equipment or communications were prohibitive or the available products proved inadequate to cover the full range of CP measurements. System selection should therefore include consideration of the following user requirements:

1. Flexibility of Measurement

Not all environmental monitoring systems are specifically designed for CP. It is important to differentiate between short term data logging systems and long term asset monitoring systems.

How flexible is the proposed monitoring system? Is it capable of measuring the required parameters at T/Rs, which must include voltage and current output, ON and OFF potentials and the AC supply? It should have the capability of monitoring all the specific CP values shown in Table A at test posts so that low points and interference can be monitored. Preferably it should include the capability to switch the output of the T/R for close interval survey work.

In recent years the traditional range of DC measurements has been extended to include AC (see below). It is therefore highly desirable that any CP monitoring system should be able to monitor both DC and AC voltages and current levels at test points.

2. Adequacy of Data

Data loggers are inherently unsuited to long term asset management. They are often aimed at solving a transitory problem and may require large amounts of data to be collected, stored and uploaded. In this sense they may usefully be used in conjunction with an asset monitoring system.

Sufficient data must be reported to provide a high level of system confidence but without "data overload". Alarms should be generated automatically for values outside acceptable thresholds so that faults in the CP system can be rectified promptly.

3. Reliable Communication

Moving data from a field location to an operational HQ needs to be accomplished reliably. Data integrity is very important and no loss of data can be tolerated. For this reason proprietary communication systems are generally avoided in favour of systems that have demonstrated their worth over many years. GSM is in this category and the SMS (Short Message Service) is ideal for low cost data communication in areas that have cell phone coverage. In practice this usually includes urban areas, major highways and other arteries.

Where there is no cell phone coverage, the preferred communication method is usually satellite, though it is more expensive, slower and less reliable than GSM. In the past there have been problems with insufficient satellite coverage but this is improving. Satellite modems require more power than GSM so an external power source may be required.

4. Physical Robustness

Pipelines often cross wild territory and CP monitors are exposed to extremes of temperature, humidity and dust. They need to be designed with few (if any) external controls and excellent ingress protection rating.

A very important consideration is protection against lightning – any system that has been "extended" to measure CP is unlikely to have been designed with the thought that it will be connected to a buried lightning conductor! Many operators have found that their monitoring equipment fails as soon as an electrical storm occurs. A good system will survive up to 30,000V of DC.

Size is another important factor. Preferably the monitoring units will be compact and, in practice, this means they should be designed for low power consumption because their physical size will be largely determined by their battery supply (primary or back-up in the event of an AC failure), which should provide typically 5 years of field use. If lithium batteries are used, these should be below Class 9 international transportation limits for hazardous materials.

5. Ease of Installation

The system should be quickly and easily installed at a T/R and, at the test point, compact enough not to require replacement or modification of the existing infrastructure. It is preferable to be able to install and configure the system so that connections can be checked with *in situ* readings directly on-site. Laptop PCs should be avoided for field installations.

Case Study: Abriox MERLIN System

Abriox has worked with gas, petrochemical and water companies in the UK and US to address these requirements. The system, now known as MERLIN, was designed flexibly so that operators could select the monitoring options they required to demonstrate compliance at the T/R (Figure 4a) and test point (Figure 4b). The monitors are very compact and can be configured on-site using a standard cell phone.

During trials in 2007 the accuracy of measurements was compared with those taken at site with a multimeter - a particular design challenge being to measure sub-Volt levels of DC accurately in the presence of much higher levels of induced AC. Communication using GSM/SMS was very reliable and the system promptly indicated failures of the AC supply to the T/R. The MERLIN test post monitor was also deployed to monitor the anode current and ON/OFF potentials at sacrificial anodes.

Figure 4: Monitoring (a) a T/R and (b): a CP point on a new LNG pipeline

Although UK winter conditions in the UK are not particularly extreme, US units in Texas were exposed to relatively high daily temperatures (Figure 4a). The physical robustness of the system was further demonstrated when some monitors experienced the effect of lightning discharges onto the pipeline, surviving the event even where the T/R output fuse was blown. All units performed continuously throughout the trial periods.

To allow full unit configuration and to record and display the data Abriox developed a comprehensive software package (CP System Manager). This allows low and high alarm thresholds to be set for all monitoring channels and includes a special diagnostic mode in which data can be viewed hourly – providing greater resolution on "problem" issues. Data can be easily exported to asset management programs.

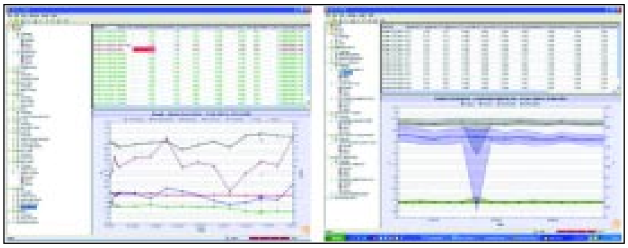


Figure 5(a) Graphical and tabular display of CP data; and (b) Identifying an AC power failure

Assessing the Benefit

The financial payback on a remote monitoring system may be determined by a combination of "hard" and "soft" financial elements.

"Hard" elements comprise purchase of the monitoring equipment, consumables (connection wires, crimps, shunts etc.), reference electrode and coupon (if potentials and current measurements are being taken) and the cost of labour to carry out the installation. A typical cost is $2,000 per installation, which after capitalisation results in an annual P&L impact of around $400. The operating expenditure required to carry out manual CP measurements varies from country to country and within companies, but $40-50 is often quoted as a typical range. On this basis remote monitoring can provide a useful payback where monthly readings are required, which includes T/Rs and frequently-read test posts.

"Soft" elements are more difficult to quantify but potentially more significant:

- Collecting data at periodic intervals is essentially reactive – faults in the CP system can go undetected for at least a month (at T/Rs) and for many months (at test posts) until the next reading is taken. This risks the pipeline being unprotected for long periods, accelerating corrosion and shortening its useful life. By responding more quickly to CP failures, enormous savings can be gained by extending the operating lifetime of the asset and reducing the incidence of corrosion-induced maintenance work.

- A very important factor is the freeing up of technicians' time to attend to other network issues; pipeline companies cover a wide geographical area so that the opportunity to improve productivity is huge. Many CP sites are difficult to access and may require permission to be obtained from the landowner.

- Many companies are reviewing the carbon footprint of their operational activities. The international environmental standard ISO14000 encourages the setting of performance indicators to reduce emissions.

- The cost of safety is problematic to calculate. Apart from the obvious exposure to traffic accidents when driving, many CP posts are sited at roadsides that were quiet when the pipeline was laid decades ago but have now become busy highways where it is dangerous to take measurements.

- CP technicians must ensure electrical safety. T/Rs incorporate two different earthing systems, so technicians must be trained, and must maintain their safety accreditation, in order to work on them. At test posts with induced AC from power lines (Figure 6a), electric shocks can be generated from "touch" and "step" voltages and high current levels.

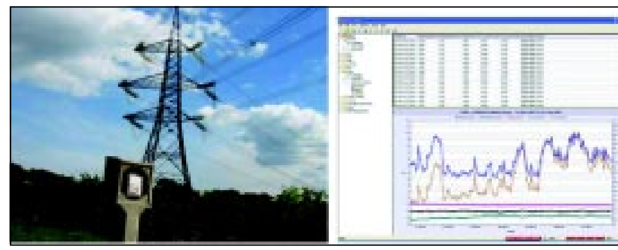
AC Corrosion

Obtaining planning consent to lay a new pipeline has become more difficult in recent years. Where a single utility delivers both electricity and gas, it has therefore been convenient to lay new pipelines alongside existing high voltage power lines (Figure 6a).

As recently as 10 years ago, pipeline engineers were disputing that corrosion could be caused (or influenced) by AC. Very little monitoring of induced AC was carried out - apart from where it could present an electrical shock hazard. However, recent studies have concluded that cathodically-protected pipelines may be affected by AC from nearby power lines. This is of particular concern in the case of newer pipelines that run parallel to high- voltage overhead transmission lines and have high quality (eg fusion-bonded epoxy) coatings. Damage may be caused to the coating of the pipeline and/or the overall corrosion rate may be accelerated.

A guideline threshold of 1 5VAC (equivalent to a current density of 1 00A/m2) has been set by NACE, above which action should be taken to mitigate AC effects; however, there is evidence that AC-assisted corrosion can occur at lower voltage levels but where the current density may be disproportionately higher due to local soil conditions. Regulatory bodies are now introducing updated guidelines to evaluate the likelihood of AC corrosion and to deal with long-term AC interference.

An important feature of the new MERLIN system is measurement of AC voltage and current. This is proving useful in identifying patterns of AC interference and is contributing to ongoing studies of this phenomenon (Figure 6b).



Figures 6a and 6b: Monitoring induced AC from power lines

Conclusion

Nowadays there are many industry sectors where remote monitoring has been deployed to enable better utilisation of human assets, as well as better management of capital assets. Monitoring cathodic protection on buried metal pipelines is just one of those areas – but has presented some significant technical challenges. The convergence of low power consumption microprocessor-based electronics with affordable telecommunications has enabled these challenges to be overcome. This is improving the management of CP systems worldwide.

Today many gas transmission and distribution companies, petrochemical and base chemical companies and water utilities are implementing remote CP monitoring in order to:

- Reduce operational monitoring costs.
- Monitor pipeline CP levels automatically.
- Respond immediately to a potential corrosion threat.
- Deploy skilled labour more effectively.
- Improve employee safety at the CP site and on the road.
- Demonstrate best practice to regulators.
- Reduce their carbon footprint.

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