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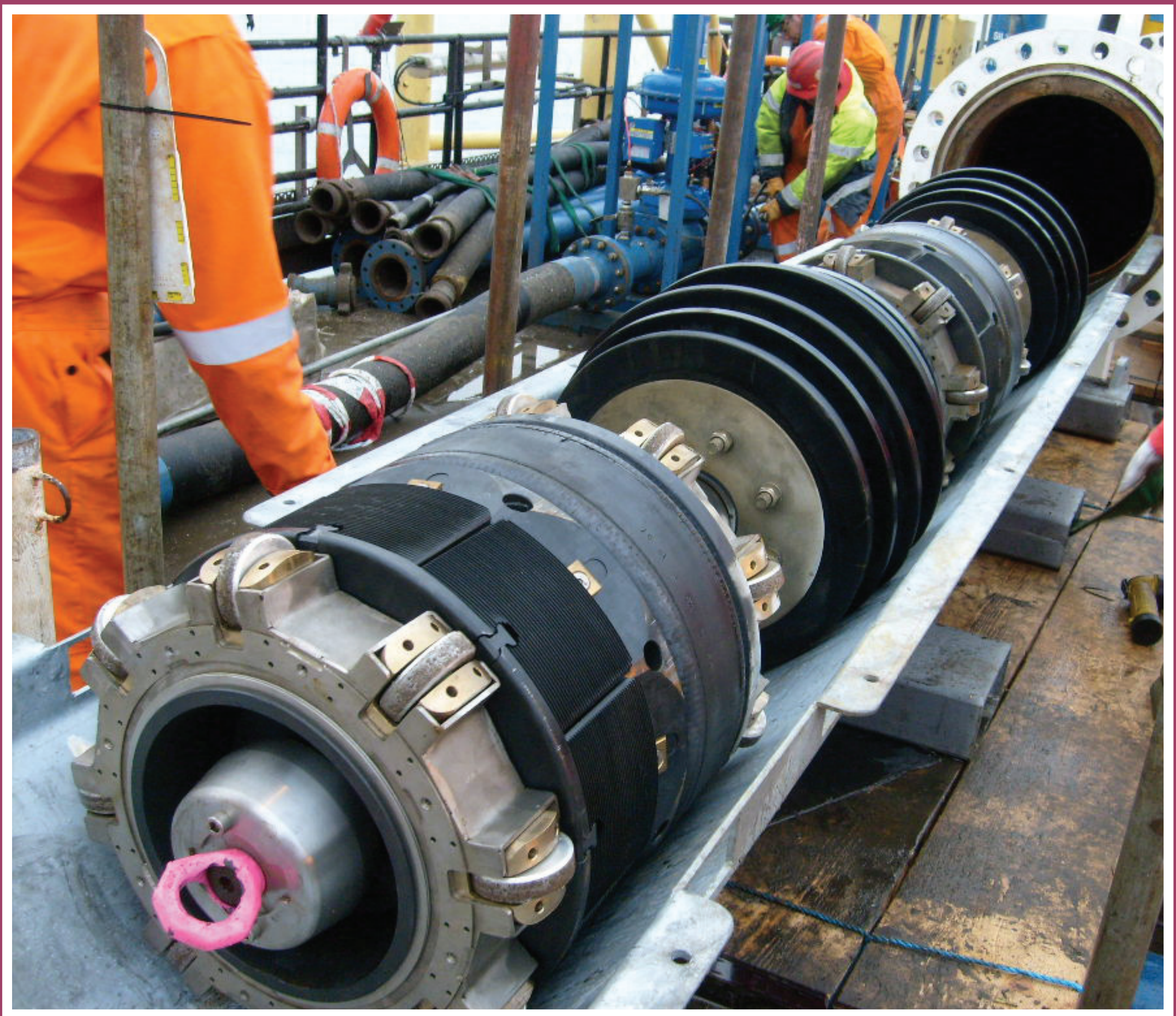

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Remote cathodic protection monitoring: preventing pipeline corrosion, improving resource management

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CATHODIC PROTECTION is an essential component of corrosion prevention on metal pipelines and is widely used in the gas, petrochemical, and water industries. To comply with regulatory standards and best practice, regular measurements of CP levels are required. Conventionally these been taken manually, requiring significant human resources and considerable cost to pipeline operators. Remote monitoring of CP can now automate the data collection, with the potential to extend the asset lifetime, reduce the monitoring cost burden, and free-up technicians' time to focus on other network issues. There are also significant safety and environmental benefits.

THE COSTS OF laying a metal pipeline, determined by its specification, wall thickness, and installation in the ground, are high. It is important to ensure that the pipeline is maintained in active service and good condition for as long as possible. Degradation of the material of the pipe is very expensive to correct and, at worst, can lead to a pipe failure with unpredictable consequences.

Corrosion is an electrochemical process that takes place when a metal is exposed to its environment, a common example of which is the rusting of steel. Pipeline operators protect against the long-term effects of corrosion primarily by applying high-quality coatings to minimize the interaction between the pipe and the surrounding soil. However, where sections of pipe are welded together, if there are aggressive soil conditions or due to the forces acting on the pipe, defects can occur in the coating. A secondary method of protecting the pipe metal against corrosion is therefore required.

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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. As the oil and gas industry expanded during the latter half of the 20th century, cathodic protection became a standard procedure for protecting metal pipelines against corrosion, allowing thinner pipes to be used.

All pipeline operators use CP extensively on their transmission pipelines. The big advantages 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 types of CP system (Fig.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, and have low operating costs and minimal

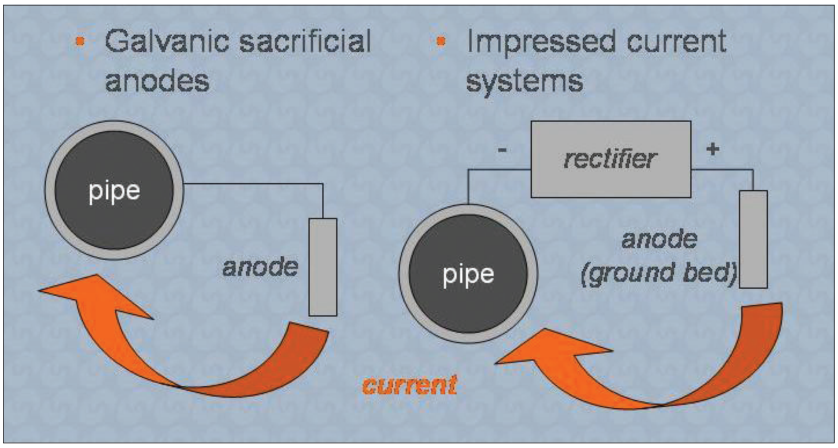


Fig.1. Types of cathodic protection system: galvanic (left) and impressed current (right).

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 economically protecting long lengths of pipeline. However, impressed-current systems rely on a continuous AC power source as well as the operation of the transformer rectifier (T/R) that energizes the system.

The level of CP current that is applied, especially from an impressed-current system, is important. Too little current will not protect the pipeline adequately and corrosion damage will ensue. Excessive current can lead to disbonding of the coating and hydrogen embrittlement. This can cause material degradation, leading to premature failure of the pipeline. CP systems may sometimes cause interference with other nearby buried structures.

CP compliance

Cathodic protection, where applied, 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. In an impressed-current system, measurements are taken at transformer-rectifiers (T/Rs) and CP test posts. In a galvanic system, measurements are taken at the anode.

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 pressurized pipelines containing gas or petrochemicals.

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: today, many pipeline companies have teams of technicians constantly "on the road", travelling to distant parts of their network to take CP measurements. Transformer-rectifiers 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 (Fig.2). Roads are becoming more congested and it is not uncommon for a technician to spend half a day travelling to a remote T/R. On his return, time must also be allowed for entering the data into the management system.

With pressure on all companies to maximize the productivity of their labour force, manual data gathering (Fig.2) is increasingly seen as a poor use of human resources. Outsourcing to CP service companies can reduce the indirect cost but has resulted in operating companies losing valuable in-house expertise, increasing their exposure to costly remedial action when maintenance is required.

Remote monitoring of CP was tried in the past but there proved to be significant technical and commercial constraints. Either the cost of the monitoring equipment or the communications were deemed prohibitive, or the available products (mainly data loggers designed for other applications) proved inadequate to cover the full range of CP measurements. In recent years these have included AC, as well as DC, measurements. Under constant regulatory scrutiny, pipeline operators had little option but to continue

*Fig.2. Many T/Rs are situated in remote locations where manual data collection (*inset*) is time-consuming.*

with their manual procedures, adding more – or more-frequent – measurements as required. This further increased the cost and operational resource burden in order to demonstrate the necessary compliance.

User requirements for remote CP monitoring

Abriox reviewed the status of the market in late 2005, and concluded that pipeline operators genuinely wanted to implement remote monitoring but had little confidence that the prevailing technology could be deployed cost-effectively or reliably. Discussions were held with gas and petrochemical companies in the UK and the US, as well as with independent consultants, on the specification for a remote-monitoring system. A strong consensus of opinion resulted, the main user requirements being:

- Flexibility of monitoring device to measure (a) all the required parameters at T/Rs; (b) CP values at test posts so that low points and interference, including induced AC, could be monitored.

- Adequacy of data: regular enough to provide a high level of system confidence but without data 'overload'. Alarms should be generated for values outside acceptable thresholds so that faults in the CP system could be rectified promptly.

- Data communication: low cost but non-proprietary and based on a reliable platform.

- Robust enough to operate reliably under extremes of temperature and humidity, and powered for at least five years in the field.

- Quickly and easily installed at a T/R and, at the test post, compact enough not to require replacement or modification of the existing infrastructure (type M28 in the UK; similar constraints internationally).

At the T/R it is important to monitor that the AC supply is always present – a power failure immediately renders the CP system ineffective. When powered, the voltage and current outputs must be within acceptable limits.

Figure 3 shows how, in a manual measurement, a multimeter is used to take spot readings of voltages and currents at a test post (a marker point that incorporates a physical connection to the pipe). Some or all of the measurements shown in Table 1 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)

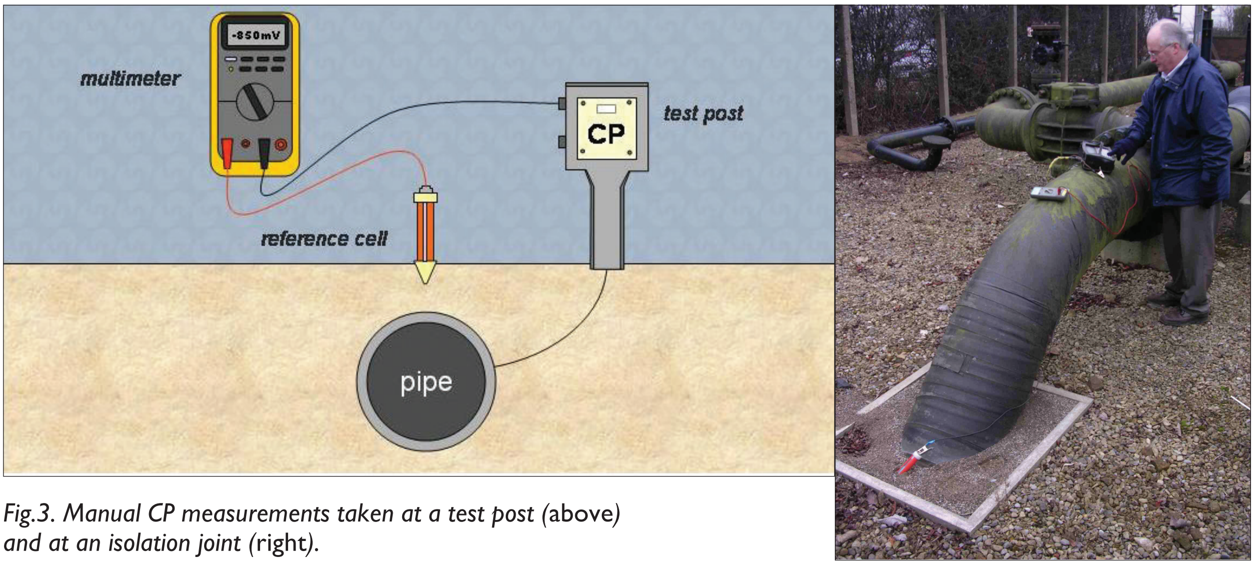


*Fig.3. Manual CP measurements taken at a test post (*above*) and at an isolation joint (*right*).*

- 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 (for example, proximity to overhead power lines)

System development

In early 2007 Abriox field tested a batch of prototype units 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 (Fig.4a) and test post (Fig.4b). The monitors can be fitted easily within a standard T/R cabinet or test post easily and are configured using a standard mobile phone.

The trials confirmed the accuracy of measurements (by comparison 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

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 energized.
Instant-off potential	The T/R output is briefly interrupted to produce a 'true' pipe-to-soil potential, free from undesirable IR drop effects and before any appreciable depolarization as 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.

Table 1. The main cathodic protection measurements.

Fig.4. (a - left)Monitoring a T/R (Merlin unit lower right); (b - right) Monitoring a CP point at an above-ground installation.

was very reliable and the system promptly indicated failures of the AC supply to the T/R, enabling cathodic protection to be restored quickly. Previously the pipeline could have gone unprotected for several weeks.

Although UK winter conditions are not particularly extreme, US units in Texas were exposed to relatively-high daily temperatures. 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.

The test post monitor was also deployed to monitor the anode current and on-off potentials at sacrificial anodes. A practical consideration is that these systems are often accessed from surface boxes in roadways, and measurements at these points need to be carefully undertaken and may require street closure in compliance with road safety regulations.

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.

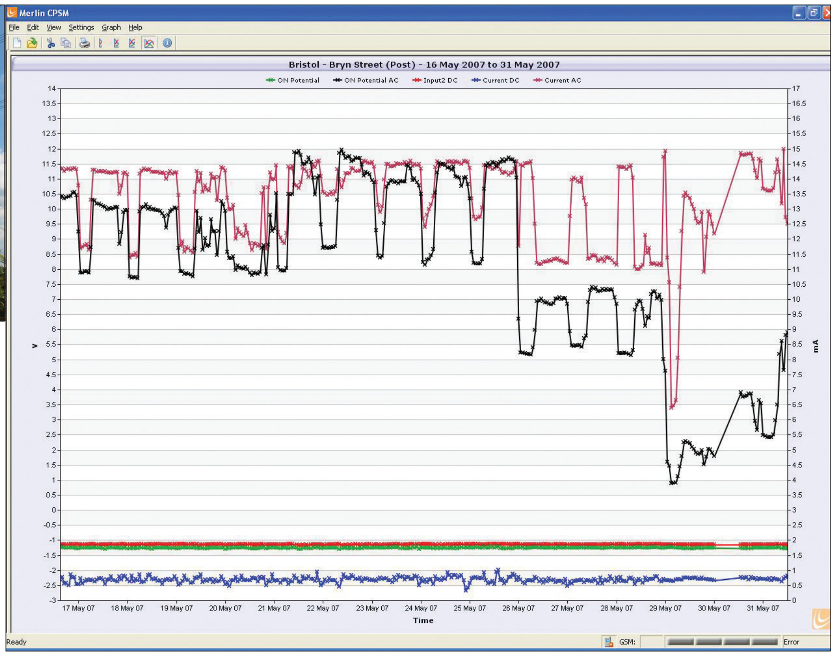
Cost benefit

The success of the system's trials is prompting a reassessment of the way in which pipeline operators maintain and monitor their CP systems. In the first instance there has to be a financial payback – which 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 £1,000 ($2,000) per installation which, after capitalization, results in an annual profit-and-loss impact of around £200 ($400). The operating expenditure required to carry out manual CP measurements varies from country to country and within companies, but £30-40 (UK) and $40-50 (US) are often quoted as typical ranges. 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 are 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



Figs 5a and 5b: Monitoring induced AC from power lines.

(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 proactive approach to compliance, with readings taken automatically and consistently, may satisfy the regulator to the extent of deferring or reducing the need for expensive alternative measures, such as pigging runs.

- A very important factor is the freeing 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 require permission to be obtained from the landowner.

- The international environmental standard ISO14000 encourages the setting of performance indicators to reduce emissions. Many companies are reviewing the carbon footprint of their operational activities. A CP technician driving 50,000km a year emits at least 8 tonnes of CO2 - with 4x4 off-road vehicles emitting 14 tonnes or more.

The cost of safety is problematic to calculate, but the following risks to CP technicians can be largely avoided through remote monitoring:

- T/Rs incorporate two different earthing systems, so technicians must be trained, and must maintain their safety accreditation, in order to work on them.

- Many CP posts are sited at roadsides that were quiet when the pipeline was laid decades ago, but which have now become busy highways where it is dangerous to take measurements.

- At test posts with induced AC from power lines (Fig.5a), electric shocks can be generated from 'touch' and 'step' voltages and high current levels.

- According to UK Department of Transport statistics a technician driving 50,000km a year has a 2.5% chance of being involved in a KSI (killed or seriously injured) accident.

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 (Fig.5a).

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 in the UK and US 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 (such as 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 15V AC (equivalent to a current density of $100A/m^2$) 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 continuing studies of this phenomenon (Fig.5b).

Conclusion

Reductions in the staffing of large utilities and the downward pressures on operating expenditure force continuous reappraisal of how to use human resources effectively. Nowadays there are many industry sectors where remote monitoring has been deployed to enable better use 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 with the development of a new system that has the potential to improve the management of CP systems worldwide.

Today many gas transmission and distribution companies, petrochemical and base chemical companies and water utilities are trialling or 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.