February 2016

Know-how, logistics and services from a single source
Properly functioning buried pipelines and cables are simply essential for utility supply and production systems. Corrosion damage to pipelines, cables, earthing systems and other buried structures not only results in high repair expenses but also in costly interruptions to operation. In addition, there may be considerable safety risks. Comprehensive protection against corrosion is therefore essential for the safe and efficient operation of pipeline networks, complex distribution systems and industrial facilities. Corrosion protection not only plays a crucial role in maintaining long-term competitiveness but also makes a key contribution to a company’s image.

Protection by coatings is just not sufficient: Corrosion is an electrochemical reaction between a metal and its environment. Current flows as a result of potential differences, causing material loss which is determined by Faraday’s law and is a function of the potential at the metal surface. Protection by coatings (such as the application of organic coatings) may separate a metal structure from its corrosive environment but it can only be fully effective if the coating is entirely free from damage. In practice, it is simply impossible to entirely avoid defects and damage to a coating.

This is why effective corrosion protection calls for a combination of passive and active protection. “Cathodic protection” (CP) is based on the targeted supply of electric current through the soil to the pipeline to be protected. The potential at the metal surface is shifted to a more negative value, limiting corrosion to a level that is practically negligible (approx. 0.01 mm per year) from a technical perspective. At complex industrial facilities where it is not feasible to isolate buried pipelines, cables and earthing systems, local or hot spot cathodic protection for complex structures is applied.

Comprehensive solutions to complex problems
Open Grid Europe plays a leading role in cathodic protection in Germany and has been instrumental in the development of systems which are increasingly comprehensive and effective. On this basis, we offer solutions tailored to the individual requirements of all types of structures ranging from pipelines (for all gases and liquids), compressor, pumping, metering & regulating stations, tank farms and power plants to special structures such as tanker jetty systems and lock gates. We design and install cathodic protection systems for structures that pose special requirements, including complex plants and materials which may not appear to need cathodic protection at first glance (such as stainless steel or aluminium). The portfolio ranges from design through construction to continuous monitoring and includes a variety of specialised services.
Several factors may be responsible

**Formation of corrosion damage**

Where electric current drains from a pipeline and enters the soil, material loss may damage the pipeline within a relatively short period of time.

The electric current may be the result of a number of different processes:

**Corrosion due to different soil conditions**

Although the difference in free corrosion potential between steel in aerated and non-aerated soils may only be a few hundred millivolts, it may still be sufficient to produce a current between two coating defects which are a considerable distance apart. In soils with poor aeration (e.g. loam, clay or soil with sulphate-reducing bacteria), current will drain from coating defects, leading to corrosion processes. In such cases, the corrosion rate may reach a few tenths of a millimetre per year.

**Corrosion by contact cells or galvanic cells**

There may also be a significant potential difference between different metals, for example between a steel pipeline and copper or stainless steel earthing systems. A corrosion risk also arises as a result of contacts between a pipeline and reinforced concrete structures due to the different potentials of steel in concrete ($U_{Cu/CuSO_4} = -0.2 \text{ V to } -0.3 \text{ V}$) and steel in the soil ($U_{Cu/CuSO_4} = -0.5 \text{ V to } -0.8 \text{ V}$). The connection between the structure and the pipeline as a result of the design of the structure creates a corrosion cell. The potential difference may cause material loss on the pipeline in the area of coating defects. This material loss can be up to a millimetre per year.

**Stray current (DC) corrosion**

DC traction systems (such as tram systems) generate stray current in the soil. In view of the polarity of traction systems (e.g. positive pole on the overhead conductor, negative pole on the rails), there is a severe risk of corrosion at coating defects especially near to traction system substations. The corrosion rate under these conditions may be in excess of one millimetre per year.

**AC corrosion**

Where pipelines are laid in the vicinity of overhead high-voltage lines or electric railway lines, AC voltages may be induced on the pipeline, causing alternating current to flow between the pipeline and the soil. Damage may occur, especially at small coating defects where the corrosion rate may reach up to 0.5 mm per year.

The aggressiveness of soil towards steel is essentially determined by the combination of the parameters oxygen concentration, conductivity and pH. Where soils have inhomogeneous layers, even soils not normally classified as aggressive can cause damage at any time. Even small potential differences in the surrounding soil along the pipeline can already lead to equalising currents between coating defects that may be located far apart and thus cause corrosion.

**The corrosion of steel in the soil is a process consisting of two reactions:**

- the solution of iron (the anodic reaction) and
- oxygen reduction (the cathodic reaction)

These two reactions may take place at separate locations.
Cathodic protection

With cathodic protection, corrosion of the protected structure is effectively prevented by active intervention in the electrochemical corrosion process. The structure-to-soil potential can be measured and influenced, allowing a defined protection potential to be applied to the protected structure. Either galvanic anodes or impressed current systems may be used for this purpose. Both systems prevent the gradual loss of material from the metal surface. The protection potential provides an "electrochemical shield" for the protected structure, effectively preventing corrosion at coating defects.

Impressed current creates protection potential

Cathodic protection was first used in 1928 by Robert J. Kuhn in New Orleans. Thanks to its effectiveness, cathodic protection is now in use throughout the world. Buried pipelines are normally equipped with impressed current systems using mains-powered transformer rectifier units. These systems are connected between the pipeline and impressed current anode system. Current flows from the anodes to defects in the pipeline coating, where it enters the pipe wall. As a result of the inert anode materials selected and the installation in continuous coke anode backfill, our impressed current groundbeds can reach an average service life of 25 years or more. The effectiveness of cathodic protection is monitored by regular measurements (for example, of pipe-to-soil potential) at representative points on the protected structure. The values measured are compared with the reference values (determined e.g. during the commissioning of the system) and analysed to detect any significant deviations.

Automatic monitoring systems

Combinations of tried and tested solutions with the innovation potential of advanced communication systems offer considerable scope for the development of optimised technologies and even more effective solutions in the field of corrosion protection. On this basis, our comprehensive GSM-based remote monitoring systems can be used for the switching operations at cathodic protection stations which are for example needed for off-potential measurements. The remote monitoring system, which we use throughout our own system, already ensures a high standard of reliability. The automatic daily reading of measured values allows almost continuous monitoring of the key parameters of a cathodic protection system. Remote monitoring means that labour-intensive, time-consuming operations at cathodic protection stations are no longer required, which opens up entirely new perspectives with respect to long-term viability analyses.

Remote monitoring provides early detection of excavator damage

A further step in fine tuning remote pipeline monitoring is a system developed in-house to detect damage to pipelines caused by construction equipment. Using remote monitoring sensors and a special signal analysis software, our specialists can detect damage to cathodically protected pipelines caused by excavators, trench cutters, ploughs or drilling tools in the monitored area of the pipeline practically "online", i.e. while the damaged is caused. Such a system provides a great deal of extra safety for man and the environment, and for the pipeline systems monitored.

More safety – less damage

The introduction of cathodic protection has led to a dramatic improvement in safety standards. This is convincingly confirmed by a comparison of corrosion damage statistics for pipelines operated in various pressure ranges (see table). Cathodic protection has been mandatory for gas transmission lines...
with an operating pressure above 4 bar since 1976. The effects are clearly shown by the DVGW damage statistics. Distribution lines and service pipes up to 4 bar are normally equipped with coatings but not with cathodic protection systems. Here, the incident rates were 7.9 and 15 per 100 km, respectively, compared with only 2.5 on lines between 4 and 16 bar. On high-pressure pipelines with operating pressures above 16 bar, which have already been equipped with cathodic protection systems throughout Germany for a considerable time, the incident rate was virtually zero. There were only 60 corrosion damage incidents on pipelines with a total length of 35,519 km.

### DVGW incident statistics

<table>
<thead>
<tr>
<th>System type</th>
<th>Length of steel pipes, km</th>
<th>Corrosion damage incidents, total</th>
<th>Corrosion damage incidents, per 100 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution systems &lt; 4 bar</td>
<td>96,076</td>
<td>7,578</td>
<td>7.90</td>
</tr>
<tr>
<td>Service pipes &lt; 4 bar</td>
<td>28,756</td>
<td>4,305</td>
<td>15.00</td>
</tr>
<tr>
<td>High pressure, 4 to 16 bar</td>
<td>28,619</td>
<td>708</td>
<td>2.50</td>
</tr>
<tr>
<td>High pressure ≥ 16 bar</td>
<td>35,519</td>
<td>60</td>
<td>0.17</td>
</tr>
<tr>
<td>Total</td>
<td>188,970</td>
<td>12,651</td>
<td>6.40</td>
</tr>
</tbody>
</table>

Source: DVGW incident statistics for 2000

Interference caused by electrified railway lines

New high-speed railway lines pose a special challenge with regard to high-voltage interference and the prevention of AC corrosion. Actual interference conditions are determined by comprehensive studies and calculations carried out in cooperation with Deutsche Bahn AG, the German national railway operator. These studies are the basis for optimising earthing systems and defining monitoring strategies.

### High-voltage interference

#### Protection against accidental contact and AC corrosion

Where pipelines are laid parallel to electric railway lines or overhead high-voltage lines, an AC voltage is induced on the pipeline. We can calculate the magnitude of the induced voltage using a computer program based on AFK (Corrosion Protection Working Party) recommendation no. 3*. Key parameters which determine the voltage include the length of the parallel section, the distance between the pipeline and the high-voltage system, the quality of the pipeline coating and the normal operating current or short-circuit current of the electrical system. The earthing measures required for preventing inadmissible levels of touch voltage (to guarantee the safety of personnel working on the pipeline) are selected on the basis of the calculated results. For touch voltage protection, AFK Recommendation no. 3 sets limits of 60 V for long-term interference and 1000 V for short-term interference (up to 0.2 s). However, AC corrosion may already occur at values below the threshold of 60 V, even if the pipeline is fitted with a cathodic protection system. Latest research has shown that the correct setting of the CP system is crucial for avoiding AC corrosion.

*Identical to DVGW code of practice GW 22 and Technical Recommendation no. 7 issued by the Interference Arbitration Body.
Cathodic protection of complex structures

is a special type of cathodic protection. It is used on a wide range of systems including pipelines, earthing systems, cables and tanks at pumping, compressor and metering & regulating stations, as well as power plants, refineries and tank farms. In these applications, corrosion risks are high and protection requirements are especially complex.

Specific corrosion risks

Isolating joints are used for the electrical isolation of a cathodically protected pipeline from stations and facilities along the pipeline route, such as compressor stations and underground storage facilities. A different approach is required for the protection of these facilities because the components to be protected are connected to the earthing and equipotential system of the station. A special risk is created by the considerable differences between the free corrosion potential of steel in concrete and steel buried in the soil. As a result, equalising currents flow between coating defects on buried pipelines and the reinforced concrete foundations of buildings. Where current drains from the pipeline at coating defects, material loss occurs. The material loss is determined by Faraday’s law and severe corrosion damage may occur very rapidly at these points. This applies especially to pipeline sections near to reinforced concrete foundations.

Inside the potential gradient of the reinforcement, i.e. in the vicinity of a concrete foundation, the corrosion risk is especially severe calling for targeted measures to prevent corrosion.
Our service package for cathodic protection of complex structures

We develop protection packages tailor-made to meet the specific requirements of each individual project. This provides customers with optimum security, both as regards reliable structure operation and the avoidance of risks and in terms of strategic decisions and the long-term return on investment.

Normally, cathodic protection of complex structures systems are based on a combination of two complementary processes: basic protection involving the cathodic polarisation of the entire plant and targeted local action to make the structure-to-soil potential more negative in limited areas (hot spot protection). In addition, it may be necessary to take additional action such as providing targeted insulating coating for certain areas of foundations.

Economic basic protection
The entire buried structure, including all reinforced concrete sections and earthing systems, is comprehensively and effectively protected by protective current supplied from a central anode grounded. Normally, deep well anode groundbeds are used for this purpose. However, if an entire facility is to be protected using this approach, the protective current required may reach a hundred of amps. Only a very small amount of the total current is actually used for the protection of buried structures. This is why it is recommended to limit this form of protection to the application of a relatively low basic protective current and to provide additional hot spot protection for critical areas of the structure, such as reinforced concrete foundations.

Hot spot protection
Where the cathodic polarisation of the entire structure is insufficient to provide effective corrosion protection, the pipe-to-soil potential may be made more negative by installing single anodes. These are positioned and the protective current is set to ensure that the pipeline is always in the potential gradient of the anode. This approach means that the potential difference required at the pipeline surface can be achieved at the same time as limiting the current required for basic protection.

Additional coating
Additional passive protection (coating) is required at locations where pipelines enter reinforced concrete buildings or are routed very close to such buildings. For example, where a pipeline enters a reinforced concrete structure, a collar of bituminous coating may be applied to the wall around the pipeline in order to insulate the wall surface from the soil. This coating separates any potential coating defects on the pipeline from the potential gradient of the concrete structure, which poses a severe corrosion risk.
Proven effectiveness
Especially where pipelines are routed close to buildings (e.g. compressor buildings), the protective current supplied for the basic protection of the structure may not produce an adequate negative shift in the on-potential. For this reason additional single anodes are installed in these critical areas (hot spot protection). Special measurements are needed to ensure that the polarisation is adequate. Under these conditions, measurements may be made using test probes (coupons with permanent reference electrodes), which are already installed during the construction phase. Adequate polarisation at coating defects in the vicinity of the coupons can be demonstrated by performing measurements on these coupons (magnitude and polarity). The anodes and test probes are controlled and monitored by a central transformer rectifier unit with individual anode control. This way the currents fed to single anodes or groups of single anodes may be set as required.

Our full-service package includes all the expertise, logistics and services needed for cathodic protection from a single source and takes account of all CP-relevant factors from design through to project implementation.

Corrosion protection expertise
In Germany, Open Grid Europe is the market leader for cathodic protection expertise and innovations. Our Corrosion Protection Competence Centre provides support for customers from the gas, water, electricity, oil, pharmaceutical and chemical industries, mining companies, water boards and navigation authorities not only in Germany but throughout the world.

A high-performance team
Our cathodic protection services are based on the technical expertise and comprehensive experience of a team of about 40 engineers, technicians, physicists and chemists (in-house laboratory). The wide range of qualifications available and close cooperation within the

Responsibility, competence and performance

Our full-service package

Illustrations on this page:
Individual local CP unit (in-house development)
For operators of pipelines and other utility systems "Pipeline Integrity Management Systems" (PIMS) are becoming increasingly important as a basis for key decisions and long-term strategies. These systems give a clearer indication of the condition of a pipeline and provide all the essential data needed. We can provide effective support for the specification of PIMS requirements related to corrosion protection.

We also design, install and commission all the equipment required for protecting your structures against corrosion and verifying the effectiveness of protection.

When your cathodic protection system has been commissioned, we carry out the measurements and surveys needed for verifying CP effectiveness (e.g. intensive measurements).

Our specialists carry out follow-up measurements at regular intervals to monitor cathodic protection systems. We also compile the data required for approval by official inspectors (e.g. TÜV).

In the event of malfunctions, we offer the fastest possible troubleshooting and repair service.

For the protection of complex structures we offer a full range of corrosion protection services from the design of cathodic protection of complex structures systems to the selection and production of transformer rectifier units, the installation and commissioning of the entire system, final inspection (together with authorities and independent inspectors where required) and regular follow-up measurements.

Our services for the protection of your structures also include protection against inadmissibly high touch voltage and AC corrosion, for example in the case of pipelines routed parallel to overhead high-voltage lines. Induced voltages may cause corrosion damage and lead to hazards for operating personnel touching the pipeline.

For the design of earthing systems to reduce the induced voltage, we use computer simulations which take all relevant factors (including the expected effects of the earthing systems themselves) into account.
Our coating specialists provide consultancy services in all questions connected with passive corrosion protection. Our service portfolio also includes the corrosion protection rehabilitation of older pipelines. We carry out surveys to assess the condition of coatings and cathodic protection systems, locate coating defects and analyse the causes of corrosion. On this basis, we develop specific recommendations for rehabilitation measures, allowing customers to optimise the safety standards of their pipeline systems in a preventive way.

We provide comprehensive documentation of the services performed so that you can demonstrate the proper functioning of your cathodic protection system at any time.

Where appropriate, we also offer individual training in all aspects of coatings and cathodic protection systems (e.g. in accordance with the requirements of EN 15257 and coating inspector training courses).

Open Grid Europe | The Gas Wheel
Open Grid Europe is one of the leading transmission system operators in Europe. We provide secure gas transmission in line with our customers’ needs and are a partner you can rely on for all grid-related services – 24 hours a day, 7 days a week.

The facts
Our customers: more than 450 national and European network operators, municipal utilities, industrial customers and gas traders | Our employees: around 1,650 throughout Germany | Our transmission system: about 12,000 km of pipelines, 30 compressor stations, 100 compressor units, 17 border crossing points. Around 1,100 exit points, 679,000 million kWh of exit quantities in 2014. Around 137 million kW of peak load in 2014.

Design/engineering
- Design of cathodic protection systems
- High-voltage interference calculations
- Design of measures to reduce AC interference
- Design of remote monitoring systems
- Assessment of corrosion risks
- Evaluation and analysis of pigging inspection data
- Examination of coating defects following excavation
- Development of rehabilitation programmes
- Consultancy services for the selection of coating systems
- Cathodic protection studies
- Preparation of tenders
- Viability studies
- Evaluation any analysis of measurements made by third parties
- Construction supervision
- Training according to EN 15257

Inspections/expert opinions
- DVGW inspections
- Expert opinions

Installation services
- Installation of cathodic protection stations
- Installation of earthing/compensation systems
- Installation of test stations
- Quality assurance services during installation

Production of CP system components including
- Transformer rectifier units for local CP systems
- Decoupling devices
- Constant current generators
- AC-resistant Megger earth testers
- Series resonant circuits

Measurements and surveys
- Maintenance according to DVGW code of practise GW 10
- Fault detection
- Measurements for trenchless pipelaying (AFK recommendation no. 1)
- Electrolytic pore testing
- Interference surveys (stray currents/alternating currents)
- Commissioning surveys

Documentation
Your contact
Corrosion Protection Competence Centre
T +49 201 3642-18341
F +49 201 3642-18444
KKS@open-grid-europe.com