Planning of Remote Monitoring of the Cathodic Protection of a New Gas Pipeline

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As the Technical Rules GW 16 of the German Technical and Scientific Association for Gas and Water (DVGW) were published, it was once again discussed which conditions have to be fulfilled for remote monitoring of the cathodic protection (CP) of a gas pipeline to reduce the time and effort for monitoring measurements according to the DVGW Technical Rules GW 10 [1]. According to the DVGW Technical Rules GW 16 [2], which were published in May 2008 and in which e.g. the categories were differentiated further, the remote monitoring of the CP of a gas pipeline would belong to category 2c, which requires proof of the effectiveness of the CP for the complete object to be protected and detection of the coating holidays not protected completely.
WINGAS first considered steps for optimisation of the remote monitoring of new gas pipelines in the middle of 2003. Meanwhile, these considerations have been revised for the planned construction of new gas pipelines.
The considerations made so far are described in this paper.

State of the Considerations about Remote Monitoring in 2003

Already in the first edition of GW 16 it was described that certain conditions have to be fulfilled for detection of new coating holidays without sufficient cathodic protection. The most important condition is that the protection potential has to be reached at all coating holidays at first. Moreover, it is taken as a basis that the relation v between the ground resistance R_f of a new holiday and the coating resistance of the object to be protected shall not exceed $v = 15$.
The considerations at that time showed that it was usually not possible to fulfil the requirements of category 2 of the first edition by means of the remote monitoring of the on- and off-potentials and the protection current in the protection systems usual until then. The following example illustrates this understanding:
A 320 km long DN 800 gas pipeline with a mean protection current density of 0.12 µA m^{-2} has a protection current requirement of I_p = 100 mA. If there is a new

holiday, the ground resistance of which is by factor v = 15 higher than that of the pipeline, the current consumption of the holiday would amount to I_f = 6.7 mA. This amount corresponds to 6.7 % of the original protection current requirement of the complete gas pipeline and is within the scope of the normal fluctuations of the protection current caused by the weather. Consequently, it is not certain that such a holiday is detected by remote monitoring of the protection current fed.
To be able to detect such coating holidays for all that, it was considered to divide new gas pipelines into several protection sections (by measurements). If the protection current was e.g. fed via two rectifiers and if these rectifiers were erected at about ¼ and ¾ of the length of the pipeline, i.e. at pipe km 80 and pipe km 240, each protection system would have to feed a current of 50 mA. If pipe current test points were also set up at both sides of the protection systems, the pipe current flowing at these test points would amount to 25 mA, see **Fig. 1**. In that way there would be four protection sections from the point of view of measurements, i.e. it would be as if insulating joints had been fitted at ¼ and ¾ of the length of the pipeline as well as in the middle. If it is assumed that there is a holiday with a current consumption of 6.7 mA, it is clearly detected. If the holiday is e.g. at the beginning or the end of the section, the pipe current would increase from 25 mA to 31.7 mA, i.e. by 26.8 %.
If the holiday is in the middle between the two protection systems, the current increase at the pipe current test points PR 2 and PR 3 would amount to 13.4 %, respectively.
Considering the on- and off-potentials and the surface of the protection sections, the specific coating resistance of the single protection sections can be calculated. If there is an increase in current because the anodes have become more low-resistance due to a relatively long rainy period, the pipe current would increase to the same degree, but at the same time the potential deviation (the difference between the on- and the off-potential) is getting bigger so that the specific coating resistance does not change. For the calculation of the specific coating resistance it has to be observed that the pipe current, as shown in Fig. 1, increases from pipe km 0 and is reversed behind each protection system.

Due to these considerations WINGAS decided to divide future gas pipelines into single protection sections with a sufficient number of remotely monitored pipe current test points and to determine the specific coating resistance in addition to the off-potential. At that time it was still unclear how far the distance could be between any two remotely monitored pipe current test points.

Results of Further Examinations

As new gas pipelines were to be planned in 2007, the question about the distance between any two pipe current test points to be monitored remotely was put again.
For that purpose e.g. the specific coating resistance of the gas pipeline WEDAL was determined, which had already been operated for about ten years at that time. This DN 800 gas pipeline runs from Bielefeld to the Belgian border and is influenced both by stray currents and by high-voltage overhead lines. About every 5 km WEDAL has got pipe current test points so that the specific coating resistance of 5 km long pipe sections can be determined. The mean specific coating resistance was determined to $6 \times 10^5\ \Omega m^2$, but a few pipe sections had a specific coating resistance of up to $3 \times 10^7\ \Omega m^2$.

During the measurements it turned out that there were also potential fluctuations in the sections without stray current influence so that the measurements could be carried out simultaneously at two adjacent pipe current test points. In some cases the difference between the pipe current of adjacent current test points was so small that it was within the limits of the measuring accuracy of the measuring instruments used (the microvoltmeter Keithley 155 and the downstream data logger MiniLog512 from Weilekes Elektronik GmbH).
If, by contrast, the difference between the pipe currents was caused by test points lying 15 km from one another, the results were clearly above the measuring accuracy of the measuring instruments and the calculated specific coating resistances were plausible. Considering that the specific coating resistance of new buried pipes is even by a power of ten higher that of the WEDAL, i.e. lie at the order of magnitude of 10^8 Ωm^2, WINGAS decided to install remote monitoring sensors every 15 km for new gas pipelines. As this corresponds more or less to the distance between the line valve stations (see also the DVGW Technical Rules G 463 [3]) and as these stations are fed with low voltage, the remote monitoring sensors should be installed there. Consequently, a pipe current test point has to be erected at each line valve station.
It also seems to be advantageous to install them within the areas of the line valve stations for the following reasons:

- the protection systems are preferably to be installed there,
- extensive infrastructure is to be installed there (e.g. data link to the dispatching office and connection for power supply),
- the object to be protected, enclosed space (telecontrol container) and access are available there.

Planning of Remote Monitoring of a New Gas Pipeline

The coating quality of new buried pipes usual today leads to some specific features for the cathodic protection, which are described exemplarily for a DN 1200 pipeline.

Examination of the Outer Coating of the Pipe

Already when the pipeline is being laid, single protection current tests are made at the positions at which the pipe is pressed through and on the single, about 5 km long pressure sections, and the specific coating resistance at the positions at which the pipe is pressed through or of the pipe section, respectively, is measured. If the specific coating resistance r_{co} is less than 10^8 Ωm^2, intensive holiday detection is carried out. If at all possible, casing tubes are to be avoided. If it is not possible to avoid a casing tube, the specific coating resistance of the pipe is determined before it is welded to the adjacent pipes. Before the warranty of the company laying the pipeline expires, intensive holiday detection is carried out again. All the holidays found are uncovered, examined for outer corrosion and re-insulated. These measures are to ensure that the outer coating of the pipe does not have a holiday. As described already, it is assumed that a coating without holiday has got a specific coating resistance of $r_{co} \geq 10^8$ Ωm^2.

Length and Design of the Pipe Current Test Points

Remote monitoring sensors are fitted at the line valve stations every 15 km, the pipe current test point is placed outside the station. If there is a branch, a pipe current test point is also put up on the branch and equipped with a remote monitoring sensor. The length of a pipe current measuring section depends on the outer diameter of the pipeline and on its wall thickness and is calculated by way of the following equation:

$$L = R\,\kappa\,\pi\,s\left(d - s\right) \qquad (1)$$

in which

L	is the length of the pipe current measuring section (distance between the internal conductors) in m
R	is the planned resistance of the pipe current test point, e.g. R = 0.5 mΩ
κ	is the conductivity of the pipe steel, κ = 6 S m mm^{-2}
s	is the wall thickness in mm
d	is the outer diameter of the pipeline

If the resistance of the pipe current measuring section is to amount to e.g. R = 0.5 mΩ and if a DN 1200 pipeline with an outer diameter of d_a = 1220 mm and a wall thickness of s = 19.1 mm is taken as a basis, the length of the pipe current measuring section is calculated to L = 216 m.

To avoid induction into the measuring cable – pipeline loop due to influence of alternating voltage, the measuring cables of a pipe current measuring section are fixed at the 12 h position on the pipe and the two cables laid into the test point are intertwined several times. In that way the alternating voltage induced into the measuring loop is reduced.

Regardless of this, the alternating current flowing in the pipeline also causes a voltage drop at the measuring section, which superimposes the voltage drop caused by the flowing protection current. This voltage drop caused by the alternating current can also be much higher than the direct voltage drop to be measured. Therefore, the remote monitoring sensor has to be equipped with an alternating voltage damping element of at least 80 dB, relative to 50 Hz.

Protection Current Requirement

If it is assumed that an on-potential of $U_{\text{CSE, on}}$ = -1200 mV measured over the pipeline is sufficient to achieve effective corrosion protection, the potential deviation amounts to approx. ΔU = 300 mV. If there is a specific coating resistance of r_{co} = 10^8 Ωm^2, the protection current density amounts to J_p = 0.003 µA m^{-2}.

If e.g. a DN 1200 pipeline with a length of 300 km is considered, the surface to be protected is calculated to A = 1 150 000 m^2 with d = 1 220 mm. Theoretically, the protection current of the gas pipeline amounts to I_p = 3.45 mA on the basis of the surface to be protected and the above mentioned protection current density.

Now, at the latest, it is realised that one rectifier suffices for the complete pipeline and that no further considerations have to be made concerning the reach of the protection system. If, for instance, the protection system was erected at the end of the pipeline, the longitudinal voltage drop of the pipeline caused by the protection current would only amount to 1.2 mV.
However, these considerations also show how small the voltage drops to be measured are at the pipe current measuring points. Thus, the surface of the first protection section with a length of 15 km amounts to A = 57491 m^2. The protection current of this section amounts to I_p = 0.172 mA. It causes a voltage drop of U_P = 0.086 µV within the pipe current measuring section.

Off-potential

The proof of the effectiveness of the cathodic protection is usually provided by measuring the off-potential. This off-potential has to be measured not later than 1 s after the protection current has been switched off. If pipelines with a specific coating resistance of 10^8 Ωm^2 are considered, it is not possible to determine the off-potential within 1 s. Due to the high quality of the outer coating the pipeline has got a capacitance to earth; the ground resistance of the pipeline runs parallel to this capacitance to earth. If the protection current is switched off, the capacitance is discharged over the ground resistance and delivers a protection current that is reduced by and by. After a period that corresponds to five times the time constant the current is decreased to values of < 1% so that the off-potential cannot be determined till then.
The capacitance of the pipeline to earth is calculated to:

$$C = \varepsilon_0 \, \varepsilon_r \, \frac{A}{s_{co}} \tag{2}$$

in which

C is the pipe – earth capacitance in F
ε_0 is the electric constant, $\varepsilon_0 = 8.854 \cdot 10^{-12}$ F m^{-1}
ε_r is the relative permittivity, $\varepsilon_{r,\,PE} = 2.3$
A is the surface of the pipeline in m^2
s_{co} is the thickness of the outer coating in m

The ground resistance of a pipeline is calculated on the basis of the specific coating resistance and the surface to:

$$R = \frac{r_{co}}{A} \tag{3}$$

in which

R is the ground resistance of the pipeline in Ω
r_{co} is the specific coating resistance in Ωm^2
A is the surface of the pipeline in m^2

The time constant τ results to:

$$\tau = R \cdot C \tag{4}$$

If the equations (2) and (3) are applied, the following results:

$$\tau = \frac{r_{co}\, \varepsilon_0\, \varepsilon_r}{s_{co}} \tag{5}$$

Equation (5) shows that the time constant only depends on the specific coating resistance, the coating material and the thickness of the outer coating of the pipe and not on the surface of the pipeline to be protected. If the specific coating resistance amounts to 10^8 Ωm^2 and if the PE coating is 4 mm thick, the time constant amounts to τ = 0.51 s. Therefore, the off-potential can only be determined after 2.55 s.
If it is also considered that the pipeline is connected with suitable earth rods via AC-diverter to reduce the influence of alternating voltage, the time constant gets much bigger so that is not possible to measure the off-potential any more.

Monitoring of Reference Values

According to GW 10 reference measuring values are to be determined. In case of objects with very good coating, as in the case considered, it is unproblematic to select the specific coating resistance of the single pipe sections as the reference measuring value. It is assumed that a pipeline with a specific coating resistance of 10^8 Ωm^2 has not got a holiday, i.e. that the passive corrosion protection is fully effective, and that its effectiveness is remotely monitored by means of the cathodic protection.
Therefore, it is the intention to determine the specific coating resistance of the single protective sections via remote monitoring once a day between 2:00h and 3:00h and to file the value determined and compare it with the earlier ones. The following considerations were made about the evaluation.
Although the outer coating of the pipe does not have a holiday, there will still be certain fluctuations, but they are relatively small. The mean value of the specific coating resistance measured during a certain period is within the range of the laboratory value of > 10^8 Ωm^2 and the standard deviation will be small.
If there is a holiday, the specific coating resistance is smaller than the above mentioned mean value. There will be rather big fluctuations caused by the weather so that the standard deviation increases. In that case further examinations will be made in the protection section in question. To be able subdivide the protection section further, a further pipe current test point is erected in the middle between two line valve stations, but it is not remotely monitored. Within the scope of further measurements it can then be determined in which segment the holiday has occurred. Intensive holiday detection is performed in this segment. When the holiday has been detected, it can be eliminated and it can be checked whether the pipe wall is intact. In favourable cases (e.g. third party's site) it should also be possible to find out who is responsible for the damaged spot.

As described above, the current requirement of the single protection sections is so small that it was assumed that it is not possible to make an exact statement about the quality of the outer coating of the pipe by switching off the protection system. Therefore, it was decided to determine the specific coating resistances by means of the switching method. In this case the on-potential of $U_{CSE, on}$ = -1200 mV is increased to e.g. $U_{CSE, on}$ = -15 V. The switch-over time mainly depends on the number of AC-diverter for reduction of the alternating voltage.

A.C. Corrosion

As long as there is no holiday on the outer coating of the pipe, no corrosion reaction can take place. The research of a.c. corrosion performed up to now has shown that holidays of a size of 1 cm^2 in low-resistance grounds, in which no protective film is formed, run the greatest risk of corrosion if the CP is adjusted to relatively negative potentials. Therefore, the on-potential is set to $U_{CSE, on}$ = -1200 mV. Laboratory tests also showed that the ground resistance of 1 cm^2 big holidays was reduced from 900 Ω (circular holiday) or 500 Ω (MetriCorr ER-Coupon), respectively, at the beginning to values of about 100 Ω if the protection current density was higher than 1 A m^{-2} and that the corrosion speed increased.
The ground resistance of a 15 km long protection section of the DN 1200 pipeline in question is calculated to 1740 Ω on the basis of the specific coating resistance and the surface. A holiday getting more low-resistance due to the CP is detected reliably by the planned remote monitoring. The parallel connection of the ground resistance of the intact pipe coating of a protection section of 1740 Ω and the ground resistance of a critical holiday of ≤ 900 Ω results in a value of 593 Ω. This value is 2.9 times lower.
Consequently, it was decided to do without a.c. probes.

Verification of the Planned Remote Monitoring according to GW 16

The Technical Rules GW 16 list the general requirements for category 2c that are a condition for reliable detection of new coating holidays not protected completely. Thus, the object to be protected shall not be below a determined minimum value $R_{CO, min}$. If the object to be protected, i.e. the complete gas pipeline with a length of 300 km, is considered, this condition is not fulfilled. If, on the other hand, a single protection section with a length of 15 km is considered, $R_{CO, min}$ is just reached dependent on the parameters taken as a basis. As described above, the ground resistance of a protective section amounts to 1740 Ω. For the sake of good order it is once again pointed out that the protection section is not limited by insulating joints, but by pipe current test points. The minimum value $R_{CO, min}$ is calculated as follows according to GW 16:

$$R_{\mathrm{CO,\,min}} \approx \frac{J_{\mathrm{p}}\ \pi\ \rho^{2}}{\left(U_{\mathrm{CSE,\,R}} - 100\,\mathrm{mV} - U_{\mathrm{CSE;\,on}}\right)\cdot 300} \tag{6}$$

in which

J_P is the biggest current density for polarisation of a holiday on the protection potential according to EN 12954 [4]

ρ is the biggest soil resistivity on the object to be protected

$U_{CSE,\ R}$ is the mean free corrosion potential on the coating holidays

$U_{CSE,\ on}$ is the mean on-potential against reference earth

If it is assumed that an object to be protected runs partly through sandy soil with $\rho = 1000\ \Omega m$, that a protective current density of $J_P = 0.1\ A\ m^{-2}$ is needed for the polarisation and that the mean corrosion potential amounts to $U_{CSE,\ R} = -400$ mV, the minimum value according to equation (6) is calculated to $R_{CO,\ min} = 1500\ \Omega$ with $U_{CSE,\ on} = -1200$ mV. If, however, a higher soil resistivity or a higher protection current density is taken as a basis, the general requirements according to GW 16 would not be fulfilled any more.
Nevertheless the author of this paper believes that it is possible to monitor the insulation of the outer coating of the pipe and detect critical holidays in time by means of the procedure described. Thus, the concrete pipeline should be put into category 2 according to GW 16.

Summary

WINGAS plans to equip new gas pipelines with remote monitoring sensors so that the specific coating resistance of single protection sections with a length of 15 km each can be determined. These protection sections are not limited by insulating joints, but by pipe current test points, i.e. the pipe current test points serve as “virtual” insulating joints.
The considerations made about remote monitoring show that the off-potential cannot be measured within 1 s for outer coatings of pipes with a specific coating resistance of $r_{co} \geq 10^8\ \Omega m^2$ because of the pipeline – earth capacitance, which is discharged over the ground resistance of the pipeline when the protection current has been switched off, which means that it delivers a protection current subsequently. Therefore, the specific coating resistance of the single protection sections is defined as a reference value according to GW 10 and monitored remotely. The specific coating resistance is measured by means of the switching method. If the specific coating resistance is reduced in a protection section, the holiday is found by way of intensive holiday detection.
It is a condition for the remote monitoring described that the coating is without a holiday, which means that appropriate check measurements have to be made already when the pipeline is being laid.
For the sake of completeness it is mentioned that traditional measuring points (e.g. potential test points along the pipeline) are also installed independently of the above mentioned procedure. In that way standard measurements always can be guaranteed.

Literature

[1] Technical Rules GW 10:2008
Cathodic protection (CP) of buried storage tanks and steel pipes - Commissioning and Monitoring

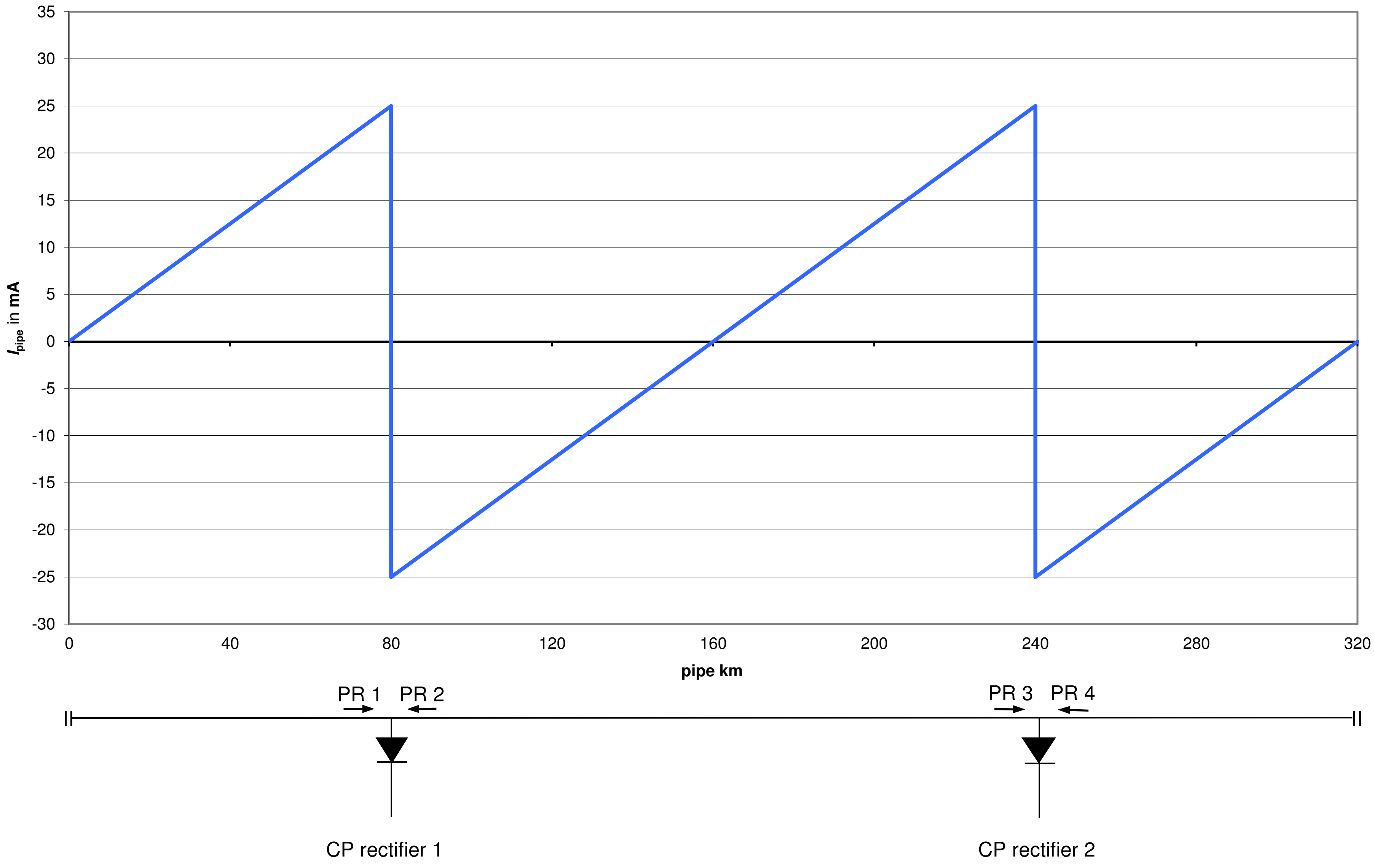
[2] Technical Rules GW 16:2008
Cathodic protection (CP) of buried storage tanks and steel pipes - Remote monitoring

[3] Technical Rules G 463:2001
Steel gas pipelines for an operating pressure > 16 bar – Erection

[4] EN 12954:2001
Cathodic protection of buried or immersed metallic structures – General principles and application for pipelines

Legends

Fig. 1 - Division of a gas pipeline into single protection sections via pipe current test points



. 1 - Division of a gas pipeline into single protection sections via pipe current test points