Evaluating the AC corrosion risk of cathodically protected pipelines

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A first experience with a new approach according to German standard GW28

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Abstract

The evaluation criteria mentioned in ISO 18086 and GW 28 (AC current density, DC current density, on-potential, AC Voltage and soil resistivity) are the cornerstone in assessing the AC (alternating current) corrosion risk of cathodically protected pipelines.

Within the framework of a research project, data from pipeline operators and from laboratory measurements were collected and thoroughly analyzed, which led to the addition of a geometrical parameter as a further suitable criterion in combination with the AC current density, DC current density, on-potential, AC-voltage and soil resistivity (GW 28-B1). An important key conclusion from this study is, that at certain circumstances AC corrosion cannot be mitigated and that along with time the very high corrosion rate will ultimately decrease to a technically negligible value.

Herein we report the basic idea of the new concept and the first experience in applying these new criteria for evaluating the AC corrosion risk of a pipeline.

Introduction

Since almost 30 years extensive research has been conducted in the field of AC corrosion of pipelines. Within these three decades the understanding of the underlying corrosion mechanism and also the experience of pipeline operators increased, so that alongside with time an evolution of the criteria in assessing AC corrosion risk of pipeline took place.

At the beginning the AC current density (> 30 A/cm^2) was taken as the main parameter for the judging the risk of AC corrosion.[1] Ultimately it was thought that reducing the AC current density was the only option to prevent AC corrosion.

Later on the DC current density along with AC current density was also identified as a crucial parameter. Lab and field experiments hinted that an increased corrosion risk existed for pipelines when the AC current density was more than 30 A/m^2 and at the same time the DC current density was more than 1 A/m^2.[2] Furthermore for higher DC current densities AC corrosion can be mitigated if the DC current density is only one third of the AC current density (Figure 1a). For assessing the current densities several coupons needed to be installed at the pipelines.

Another step forward was to convert the AC/DC current densities to an on-potential (E_{on}) and an AC voltage (U_{ac}) criteria, which lead to the conclusion that for an average E_{on} more positive than -1.2 V[1], average AC voltages up to 15 V can be accepted without causing corrosion. Conclusively the pipeline operators could just adjust the E_{on} to a less negative value and try to reduce the AC voltage below 15 V (Figure 1b).

[1] All on-potentials mentioned in this manuscript are referred to Saturated Copper sulfate reference electrode

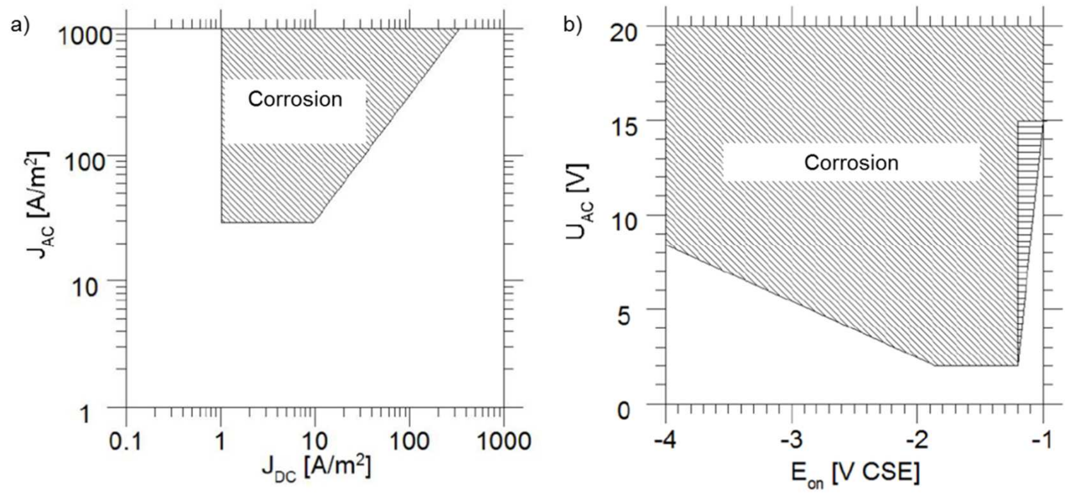

Figure 1: a) Current density and b) AC voltage / E_{on} criteria (GW 28)

These criteria were in good agreement with the scientific model of protective oxide formation and reduction [3-4]

However, another further challenge was that not every pipeline in operation could be adjusted to E_{on} more positive than -1.2 V due to stray current corrosion risk.

In the last years the existing criteria in EN 15280 and ISO 18086 were revisited and further research was conducted in the framework of revising the German standard GW 28 (mitigation of AC corrosion) in close collaboration with DVGW, German pipeline operators and the Swiss Society for Corrosion Protection. A focus of this project was to further optimize the existing criteria in combination with the operators' observation and experience, that no severe AC corrosion leading to leakage was observed on pipelines with wall thickness > 5 mm, even though the corrosion rates measured with coupons on pipelines might indicate very high corrosion rates.

A modelling approach was chosen in the above mentioned project, which is in good agreement with the scientific and operational experience. As a result it was concluded that the criteria in the past were generally correct and in good agreement with the scientific oxide growth model mentioned above [3-4]. In the new approach also the soil resistivity and the geometrical evolution of the corrosion site was also considered. A more detailed report on the formula and experiments can be found in [5,6].

An important core conclusion was that the increase in steel surface area caused by corrosion ultimately leads to a decrease in current densities over time. When the DC current density or the AC current density ultimately reached values smaller than the thresholds in ISO 18087 (J_{DC} < 1 A/m^2 or J_{AC} < 30 A/m^2) the corrosion risk by AC voltage can be neglected. As a consequence allowing the loss of a certain amount in wall thickness without neglecting the mechanical integrity of the pipeline describes the new approach in mitigating AC corrosion risk.

Pipeline in focus

The new approach in assessing the AC corrosion risk according to the revised standard GW 28 has been applied to a non-piggable pipeline. First the AC corrosion risk was assessed with the former criteria and in a second step compared to the new criteria.

The pipeline in focus of AC corrosion risk assessment runs through an urban area and has a length of approx. 4 km. Further important data relevant for the assessment are given in table 1.

Table 1: Relevant pipeline data

Construction year	1985
Diameter	DN 400
Nominal pressure	PN 70
Wall thickness	6.6 mm
Material	StE 360.7
Coating	3-layer PE

The cathodic corrosion protection is provided over the main pipeline through bonding. As depicted in figure 2 the pipeline runs partially parallel and crossing a high voltage power line, AC and DC operated railways.

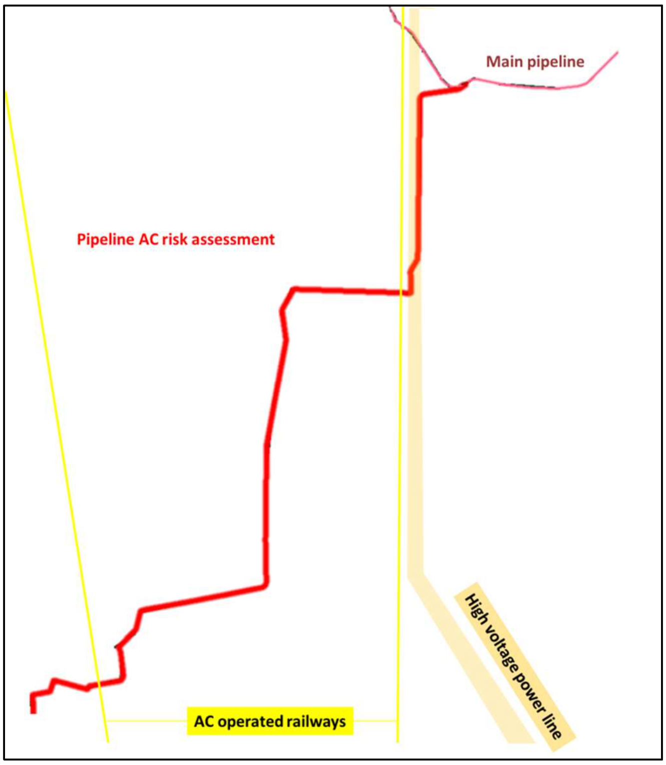

Figure 2: Overview of the pipeline for AC corrosion risk assessment

AC corrosion risk assessment with former criteria

One of the approaches for evaluating the AC corrosion risk of this pipeline in accordance with the former version of GW 28, would have been to record the AC and DC current densities by burying a number of coupons along the pipeline. As this method is exhausting and on the other hand the corrosion rates determined by this method are usually higher than on the actual pipeline this method was not the first choice. As the critical AC and DC current densities can be transformed in to AC voltage (U_{ac}) and on-potential (E_{on}), it was decided to record the AC voltage and Eon by installing data recorder/logger along the pipeline for at least 24 h (in this particular case for 90 h). The latter method is more practical, due to the fact that no excavation is needed.

Figure 3 shows as an example of the recorded data. As mentioned above the E_{on} is influenced by stray currents and furthermore the potential is set to relatively negative values due to historical reasons. Furthermore the recorded data show, that significant AC voltage is induced from the electrified railways.

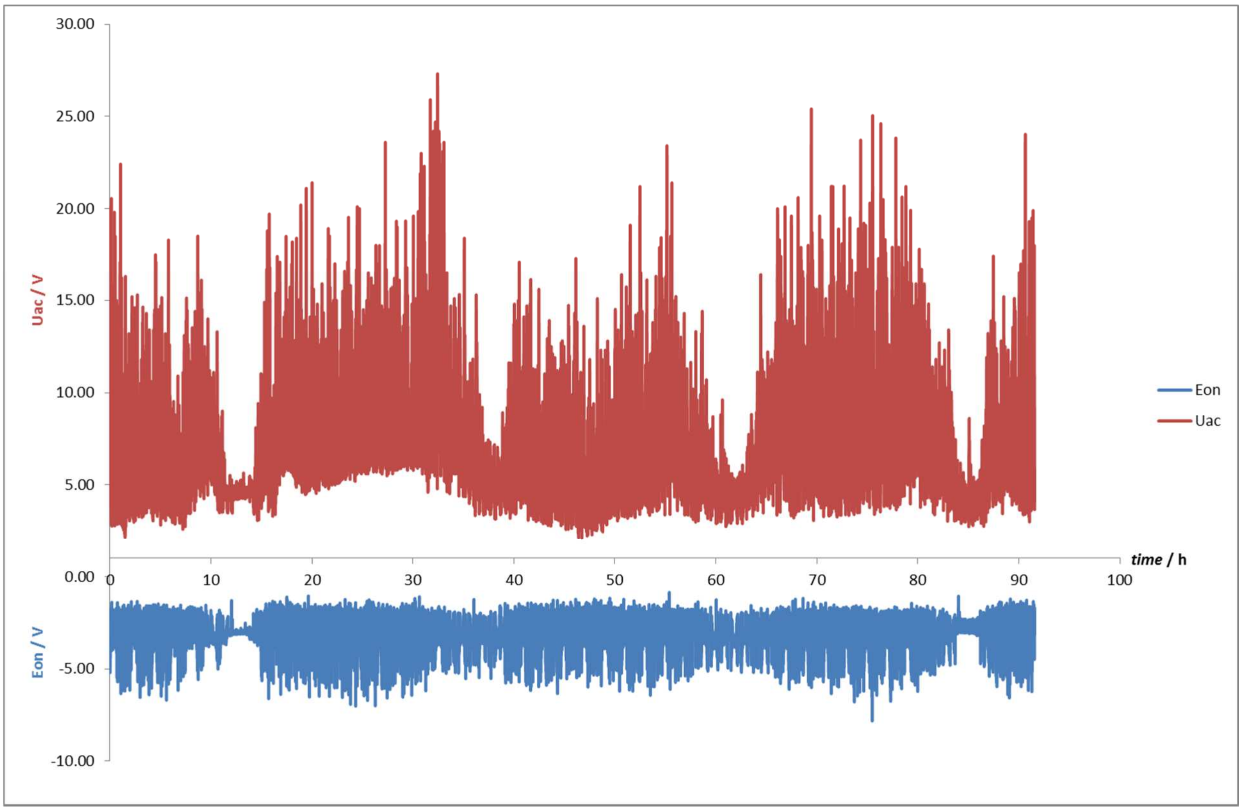

Figure 3: Recorded U_{ac} and E_{on} data at test post 4

The average E_{on} and U_{ac} along the pipeline is visualized in figure 4 and table 2.

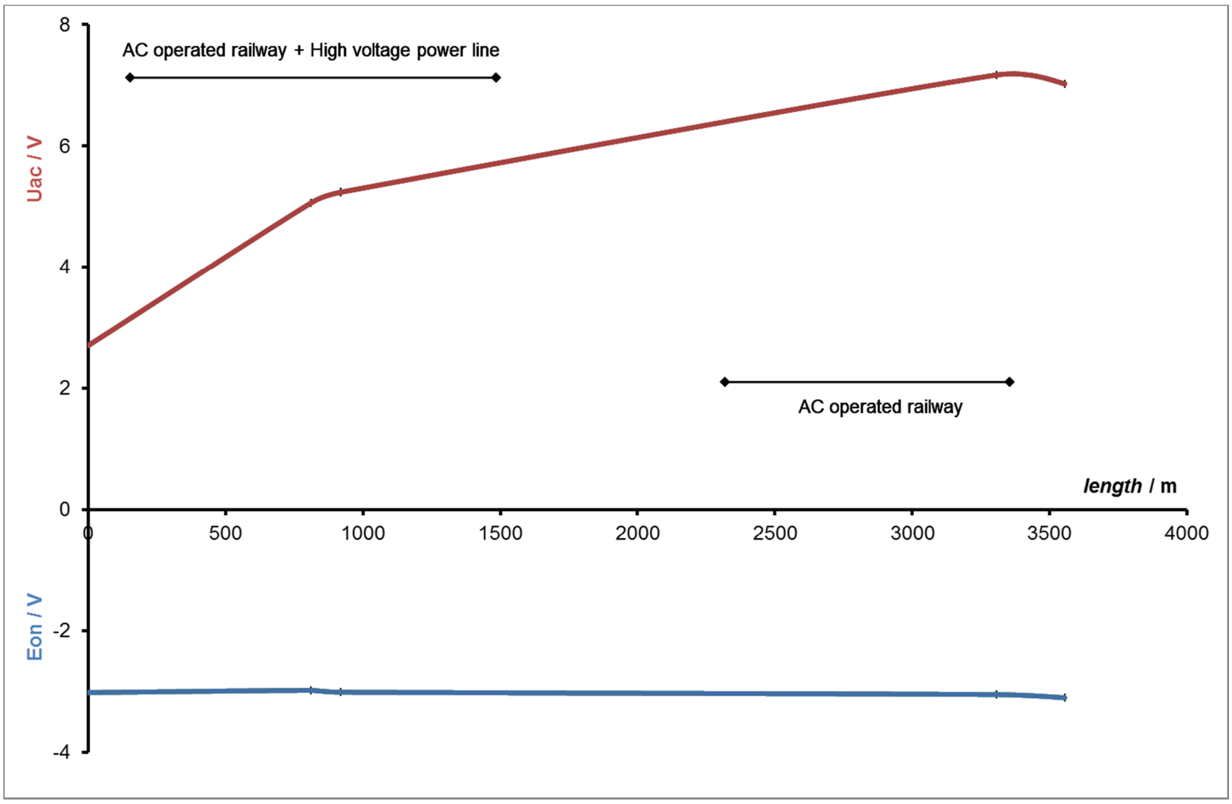

Figure 4: Averaged U_{ac} and E_{on} as a function of pipeline length

Table 2: Summary of recorded data

Test post	1	2	3	4	5
E_{on} average V	-3.00	-2.98	-3.01	-3.05	-3.10
U_{ac} average V	2.03	5.06	5.24	7.17	7.03
U_{ac} max V	6.92	16.20	20.10	27.30	26.40
Averaged Soil resistivity [Ω m]	600	600	150	200	200

By applying the Eon/Uac criterion, the outcome of the assessment would be that the pipeline has an AC corrosion risk at location 4 and 5 (figure 5). An adjustment of the potential towards more positive value e.g towards -1.2 V is not possible, because of increased danger of stray current corrosion (the maximum possible average E_{on} for pipelines in stray current corrosion risk is suggested to be -1.5 V).

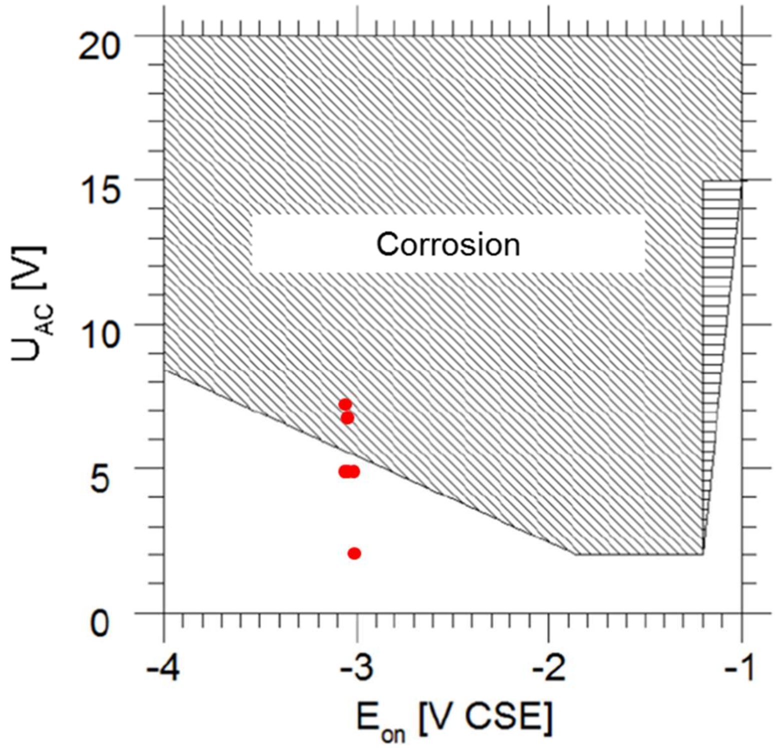

Figure 5: AC Corrosion risk assessment according to former approach as described in GW 28. The red dots indicate the averaged Uac and Eon values.

As a conclusion the plan of action for mitigating the AC corrosion risk would be:

- Electrical decoupling from the main pipeline
- Installing (at least) one rectifier
- Installing (at least) one insulating coupling
- Installation of ground electrodes for further reduction of induced AC voltage

<u>AC corrosion risk assessment according to revised GW 28</u>

The assessment with the new modelling approach is based on considering two observations:

1) The acceptable AC voltage depends on the spread resistance of a defect and thus on soil resistivity
2) The AC corrosion rate is reduced to a technically negligible level after reaching a certain depth-to-diameter ratio

Combining lab and field data a modelling algorithm was developed, which is described in more detail in [5] and [6].

As shown in figure 6 the soil resistivity will influence the acceptable calculated U_{ac} as a function of E_{on} significantly. As expected for low soil resistivity already very low AC voltages can cause corrosion even with relatively less negative adjustment of E_{on}. But with increasing soil resistivity a much higher induced AC voltage can be tolerated. In this case at 1500 Ω m and at E_{on} of -1.5 V U_{ac} greater than 12 V will not lead to corrosion.

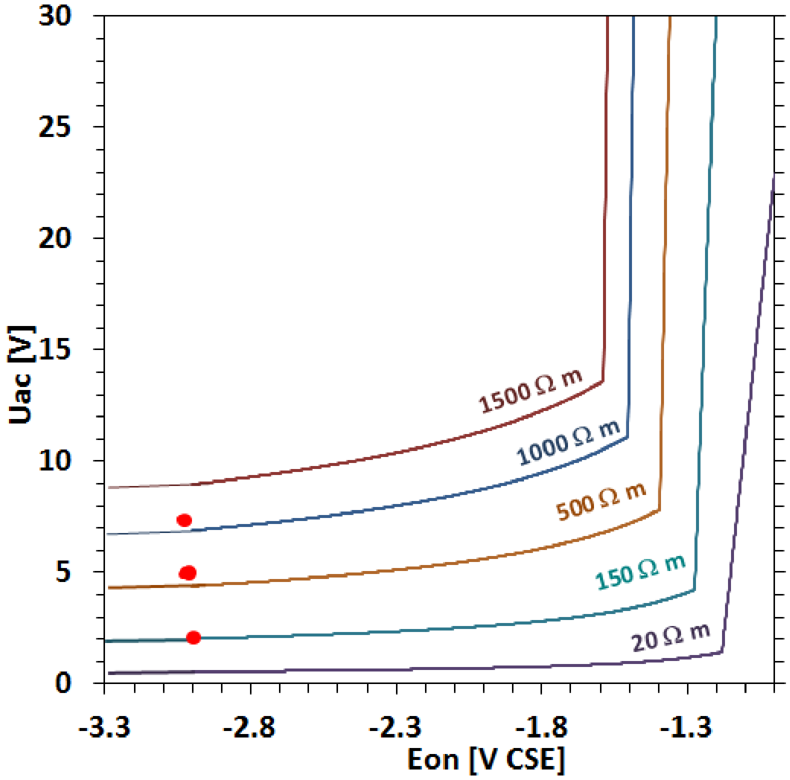

Figure 6: Modelling the acceptable AC voltage as a function of Eon for different soil resistivity. The red dots indicate the measured average values for a defect size of 1 cm^2.

The soil resistivity was measured by using the Wenner method along the pipeline. As a result the soil resistivity ranges from 150 – 600 Ω m. As can be seen from figure 6 the measured average U_{ac} values as a function of E_{on} are in the area were corrosion is expected for the range of soil resistivity measured. A further prevention of AC corrosion by just adjusting the E_{on} needs more positive potentials than -1.3 V, which is not a possible due to the severe dc interference solution for this pipeline as mentioned above. So further actions for reducing U_{ac} as mentioned in the previous section need to be considered.

Lab and field data further indicate that every maximum corrosion depth is connected to a so called critical diameter of a defect. Correspondingly meeting the current densities of ISO 18086 for a 1 cm^2 coupon, does not exclude corrosion of up to 2 mm on smaller coating defects. Once the corrosion has reached the corrosion depth associated with the critical diameter the current densities will reach non critical levels and the corrosion rate decreases to non-relevant rates. After that the corrosion rate will reach a technically negligible value (figure 7). By using the calculation based on DNV-RP-F101 (also used for calculating the acceptable material loss at defects identified by pigging) the acceptable external material loss for this pipeline can be calculated. As shown in figure 8 a corrosion depth of 4 mm is acceptable and still the safety and pipeline integrity is maintained.

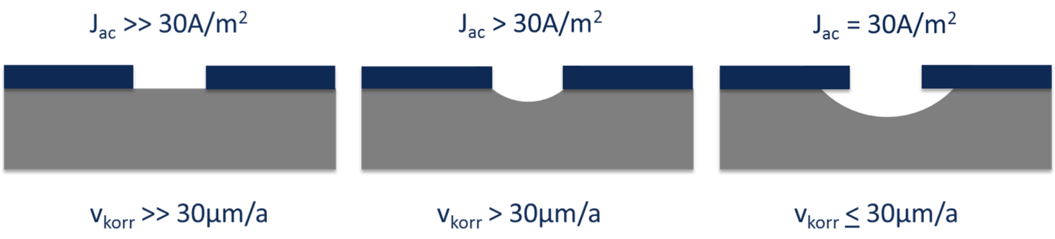

Figure 7: Schematic depiction on corrosion growth. The depth-to-diameter ratio of the corrosion is around 0.4. In summary the high AC current density decreases with increasing growth of corrosion and stops once the area is as big as that the AC current density is lower than 30 A/m^2.

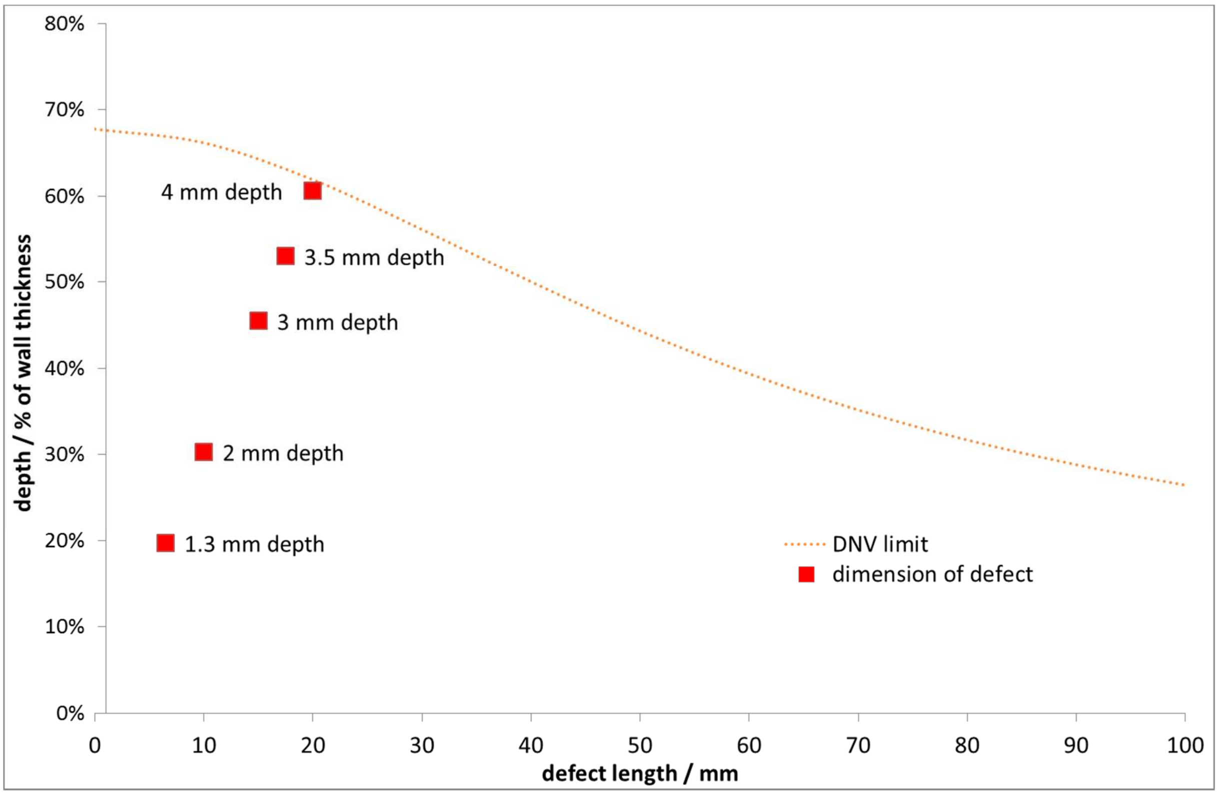

Figure 8: Calculation of maximum acceptable external material loss according to DNV-RP-F101 with the pipeline data presented in table 1.

If it is assumed that the lowest measured soil resistivity is homogenously distributed along the pipeline, the diagram shown in figure 6 can be recalculated under considering a maximum corrosion depth (figure 9). The measured average U_{ac} values on the pipeline are acceptable without further action, if a maximum corrosion depth of 3.5 mm is accepted (~55 % wall thickness reduction) on an operational level. This consideration assumes extreme worst case conditions. Conclusively the list of further action will be reduced to adjusting the E_{on} to -1.5 V. In this case also excavations were suggested to check the reliability of the calculation.

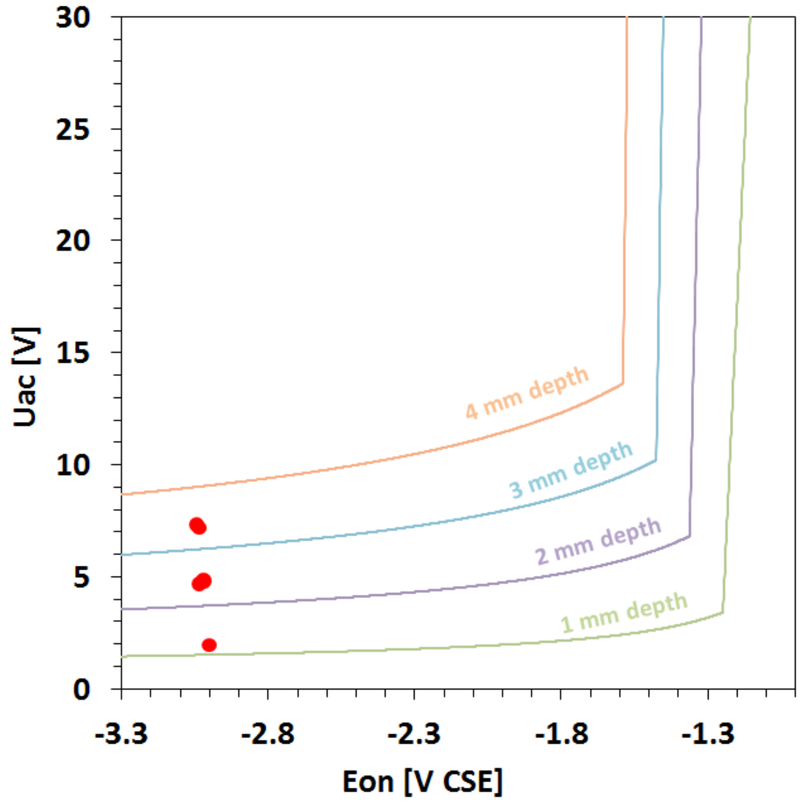

Figure 9: Modelling the acceptable AC voltage as a function of E_{on} for different maximum corrosion depth with a minimum soil resistivity of 150 Ω m. The red dots indicate the measured average values.

Conclusion

The new modelling approach allows the assessment AC corrosion risk of pipelines by considering the lowest soil resistivity along the pipeline and accepting certain maximum corrosion depth while maintaining the pipeline integrity. Based on the most recent concepts and the practical experience collected in the past 40 years with AC corrosion this approach provides an alternative procedure to ensure protection against AC corrosion without compromising the integrity of a pipeline.

At first glance it appears that accepting a certain level of corrosion represents a deviation from the procedure used in the past. However, the careful examination of the underlying mechanisms reveals that specifying a coupon size of 1 cm^2 in ISO 18086 implicitly already accepted a corrosion depth on the pipeline of up to 2 mm on coating defects smaller than 1 cm^2. In analogy the new approach represents the use of larger coupon sizes for demonstrating compliance with ISO 18086.

The above mentioned findings are in good agreement with the observation of the pipeline operators in the past and are now added to the revised German standard GW 28 / AfK 11.

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